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SURFACE SUBSIDENCE IN ILLINOIS

RESULTING FROM

COAL MINING

BY

LEWIS E. YOUNG

ILLINOIS COAL MINING INVESTIGATIONS

(Prepared under a cooperative agreement between the Illinois State Geological Survey, the Engineering Experiment Station of the University of Illinois, and the U. S. Bureau of Mines.)

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By Lewis E. Young

CHAPTER I—INTRODUCTION

Area Investigated

During the summer of 1914 there was made a preliminary study of surface subsidence resulting from coal mining operations in Illinois. Mines were visited in 24 of the 52 counties in which shipping mines are located. These 24 counties produced 94 per cent of the coal mined in the State in 1913. Within these 24 counties are 324 of the 371 shipping mines listed in 1913 and 293 of the 469 local mines. The counties visited were Bureau, Christian, Clinton, Franklin, Fulton, Grundy, Jackson, La Salle, Livingston, Macon, Macoupin, Madison, Marion, Montgomery, Peoria, Perry, Randolph, St. Clair, Saline, Sangamon, Vermilion, Washington, Will, and Williamson. In all but three of these counties coal mining has resulted in subsidence of such intensity as to result in substantial damage to surface property.

Data were secured from 108 companies operating 149 separate plants, and in addition, the field notes of the Cooperative Investigation upon 100 Illinois mines supplied data on 8 mines not visited for this particular purpose.

Scope and Object of Report

Prior to this preliminary survey no work upon the subsidence problem in Illinois had been undertaken by any scientific bureau. For over a quarter of a century there has been litigation between the operators of coal mines and the owners of the surface when surface subsidence has been attributed to coal mining operations. There is a need for more definite knowledge concerning (1) the extent to which the complete removal of coal may disturb the overlying rock strata, (2) the percentage of coal that may be mined without disturbing the surface, (3) the methods of mining that should be employed in order to minimize the surface movement following the removal of the coal, (4) the methods of protecting the surface by artificial supports, and (5) the best methods and policies to be employed in conserving the mining and agricultural resources of the State.

At the present time there is more or less unrest in certain coal mining districts in Illinois on account of minor damage to the surface.

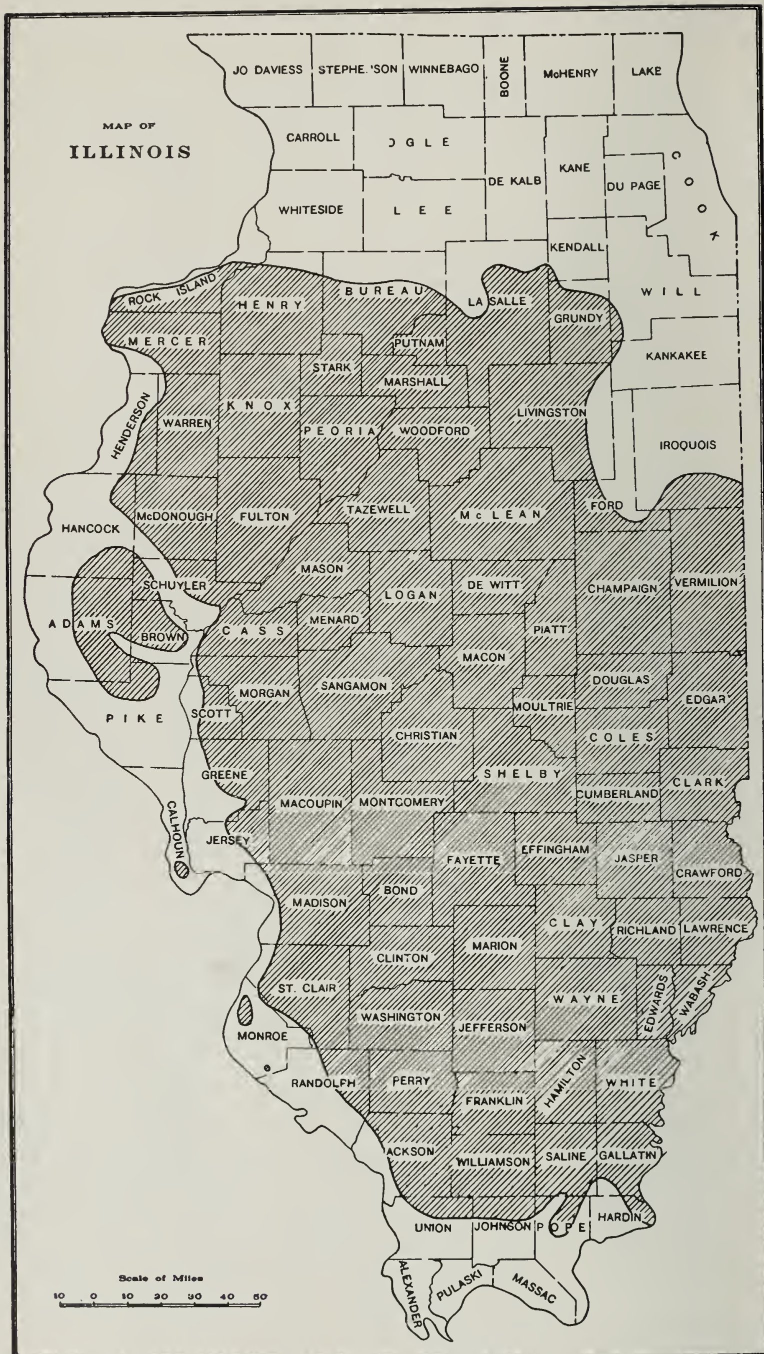


Fig. 1.—Map of Illinois showing extent of the "Coal Measures."

At a number of points mine operators are being forced to pay claims for damages much in excess of the actual cost of restoring the injured property. There is an urgent need for definite data upon the experience of operators in the various districts, so that those who mine coal in the future may be able to recover the maximum percentage of the coal with the least damage to the surface or with the briefest interference with the use of the surface property.

It is undoubtedly to the interest of the State to conserve the coal supply by securing as complete extraction as possible from the areas in which mining is now being carried on. Almost one-half of the coal is being left in the ground and made unavailable for future mining, and in some places a large part of this abandoned coal is left because the mine operators fear that by removing a larger percentage they may cause surface subsidence and be required to pay damages out of proportion to the real value of the surface. In many places the surface may be restored at little expense. But until the prevailing conditions are known accurately and the essential facts are understood and studied, the State cannot consider or propose measures to relieve the mining industry of this severe burden.

With these problems and difficulties in view, this preliminary survey was made, and the data collected show in an impartial manner the situation as it exists in Illinois at the present time.

Acknowledgments

The writer wishes to acknowledge his indebtedness to Mr. G. S. Rice, Chief Mining Engineer, U. S. Bureau of Mines; Professor H. H. Stoek, head of the Department of Mining Engineering, University of Illinois; and Mr. F. W. DeWolf, Director of the Illinois State Geological Survey, under whose combined direction the work of the investigation has been carried on. Mr. S. O. Andros of the Department of Mining Engineering, University of Illinois, has been very helpful. The various State and county mine inspectors have been uniformly courteous in furnishing much useful information. Messrs. H. I. Smith and J. R. Fleming, Assistant Mining Engineers, U. S. Bureau of Mines, have made valuable suggestions and have furnished numerous photographs for which acknowledgments are made in proper place. Mr. R. Y. Williams, formerly mining engineer, U. S. Bureau of Mines, furnished much of the data on Saline County. To the following representatives of the coal mining industry in Illinois the author is deeply indebted for many courtesies and for close cooperation: Mr. W. M. Cole, Mining Engineer, Spring Valley Coal Company; Mr. J. Quaid, General Superintendent, Big Creek Coal Company; Mr. C. H. Nicolet, Engineer, Matthiessen and Hegeler Coal Company; Mr. R. D. Brown, Chief Engineer, O'Gara

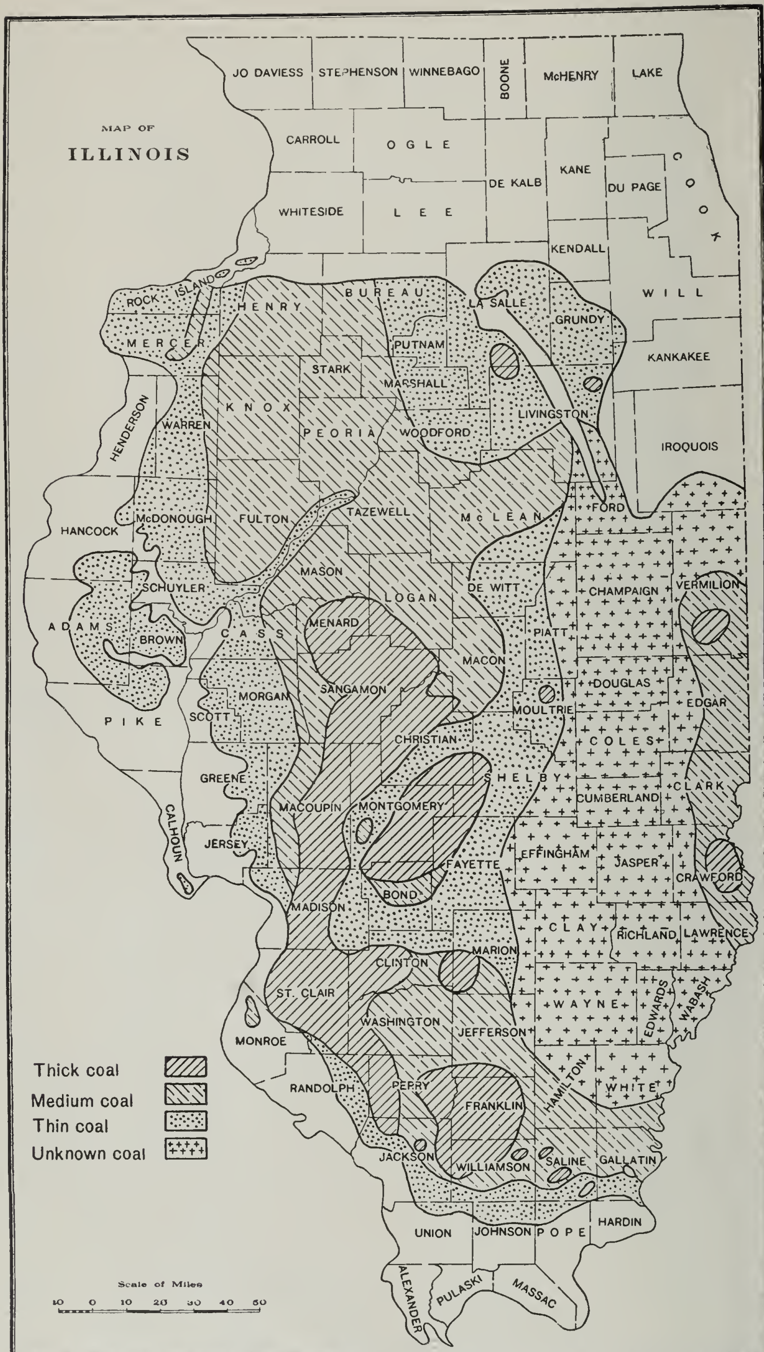


FIG. 2.—Map of Illinois showing distribution of thick, medium, and thin coal. (After Bement.)

Coal Company; Mr. R. Williams, Mining Engineer, Saline County Coal Company; Mr. R. Forrester, Superintendent, Paradise Coal Company; Mr. A. J. Moorshead, President, Madison Coal Corporation; Mr. G. E. Lyman, Chief Engineer, Madison Coal Corporation; Mr. John P. Reese, Superintendent, Superior Coal Company; Mr. S. F. Jorgensen, Chief Engineer, Superior Coal Company; Mr. T. P. Brewster, General Manager, Mount Olive and Staunton Coal Company; Mr. James Dubois, Superintendent, Dering Coal Company; Mr. Thomas Moses, General Superintendent, Bunsen Coal Company; Mr. M. F. Peltier, Chief Engineer, Peabody Coal Company; Mr. J. A. Garcia, Mining Engineer; Mr. D. J. Carroll, Chicago, Wilmington & Franklin Coal Company.

Illinois Coal Field and Production Data

Estimates made by the Illinois State Geological Survey show that the known coal areas of Illinois contained approximately 175,000,000,000 tons of coal in beds not less than three feet in thickness. The coal-bearing formations underlie part or all of 86 counties, an area of about 36,800 square miles (fig. 1). It may be noted that 674 square miles are underlain by several coal beds over 3 feet thick or an aggregate thickness of 15 feet; 3,883 square miles are underlain with an aggregate thickness of 11 feet; 12,546 square miles with an aggregate thickness of 7 feet; and 10,184 square miles with 3 feet of coal. Figure 2 shows approximately the extent of the thick, medium, and thin coal; and figure 3 shows the area underlain by the principal coal seams.

Practically the entire output of Illinois coal in 1913 was produced from 5 seams, as shown in the accompanying table.[1]

Table 1.—*Output of Illinois coal by coal seams*

(Year ended June 30, 1913)

	Tons
Coal No. 1	500,000
Coal No. 2	5,650,000
Coal No. 5	13,500,000
Coal No. 6	41,400 000
Coal No. 7	750,000
Total from 5 seams	61,800,000

[1]Total for the State as given by Illinois Coal Report, 1913, was 61,846,204 tons.

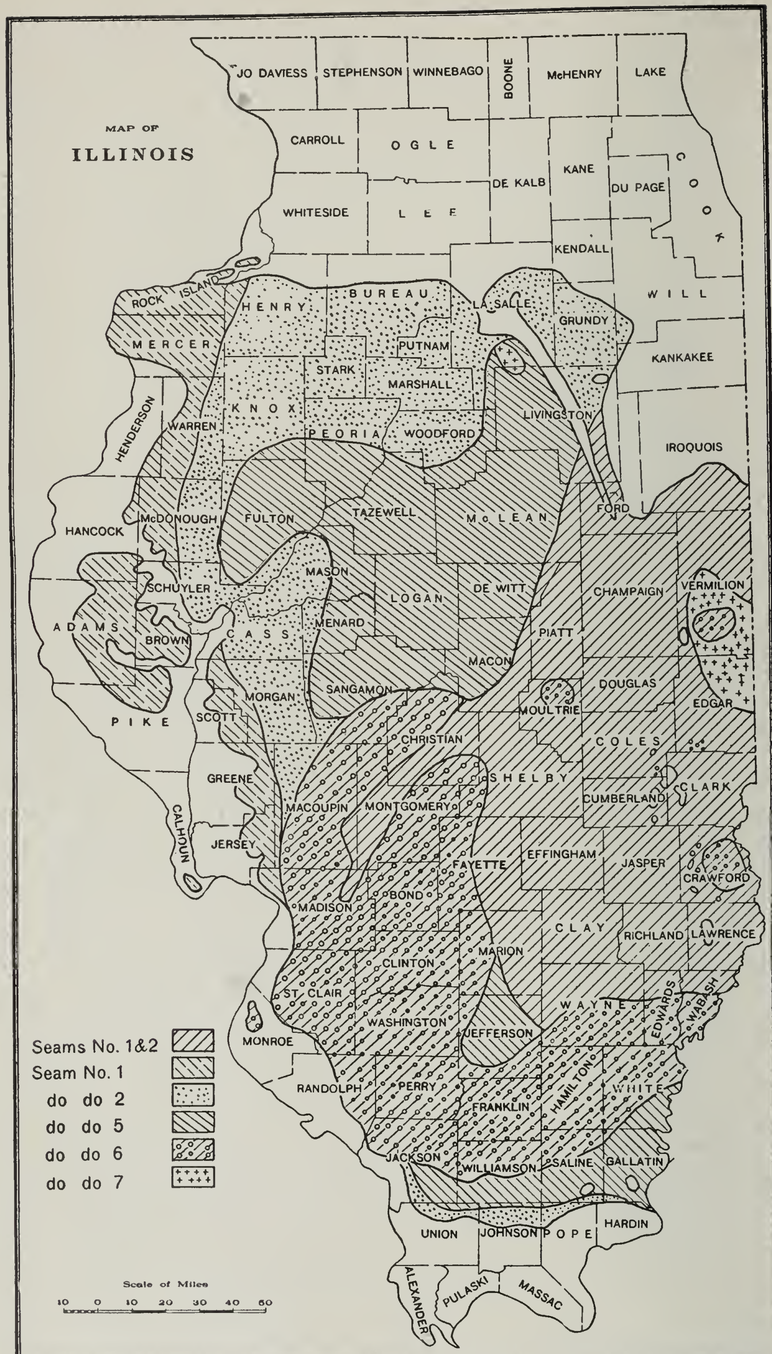


Fig. 3.—Map showing area underlain by principal coal seams. (After Bement.)

The greater portion of the output comes from shafts 100 to 400 feet in depth. Table 2 shows the relation of tonnage to depth.[1]

TABLE 2.—*Output of Illinois coal by depth of shaft*
(Year ended June 30, 1913)

Depth of shaft *Feet*	Number of shafts	Output *Tons*
0- 99	489	6,500,000
100- 199	159	17,400,000
200- 299	73	11,500,000
300- 399	46	11,500,000
400- 499	33	8,750,000
500- 599	18	2,750,000
600- 699	12	2,350,000
700- 799	6	720,000
800- 899	2	180,000
900- 999	1	105,000
1,000-1,099	1	75,000
Total		61,830,000

CHAPTER II—GEOLOGICAL CONDITIONS AFFECTING SUBSIDENCE

It is evident that whatever movement may result from underground mining will be influenced greatly by the nature of the rock overlying the coal seam being worked. As noted in Table 2, the greater part of the output of Illinois coal is from shafts not exceeding 400 feet in depth, and practically 50 per cent of the output is from shafts not over 300 feet deep. Throughout the greater part of the State the coal beds lie practically flat.

Description of Illinois "Coal Measures"

The following extracts[1] give a concise statement of the essential facts concerning the coal-bearing formations. Plate I shows general geological sections for southwestern Illinois, Plate II shows sections in the Williamson-Franklin field, Plate III shows sections in the coal fields of northern Illinois, and Plate IV shows sections in the Danville field.

The coals of Illinois exist as widespread beds or as local pockets among layers of shale, sandstone, and limestone which together make up the Pennsylvanian series. There are five coals known to be important enough to have special names, and numerous other beds occur at various depths. The maximum thickness of Pennsylvanian rocks is known to be at least 2,200 feet, though it is not to be assumed that a single bore hole could penetrate all of the various formations at the place of extreme thickness.

The Pennsylvanian series has been divided for convenience of description into three formations which present different characteristics as to time of deposition, physical composition, and economic importance. The divisions from the bottom upwards are the Pottsville, Carbondale, and McLeansboro formations.

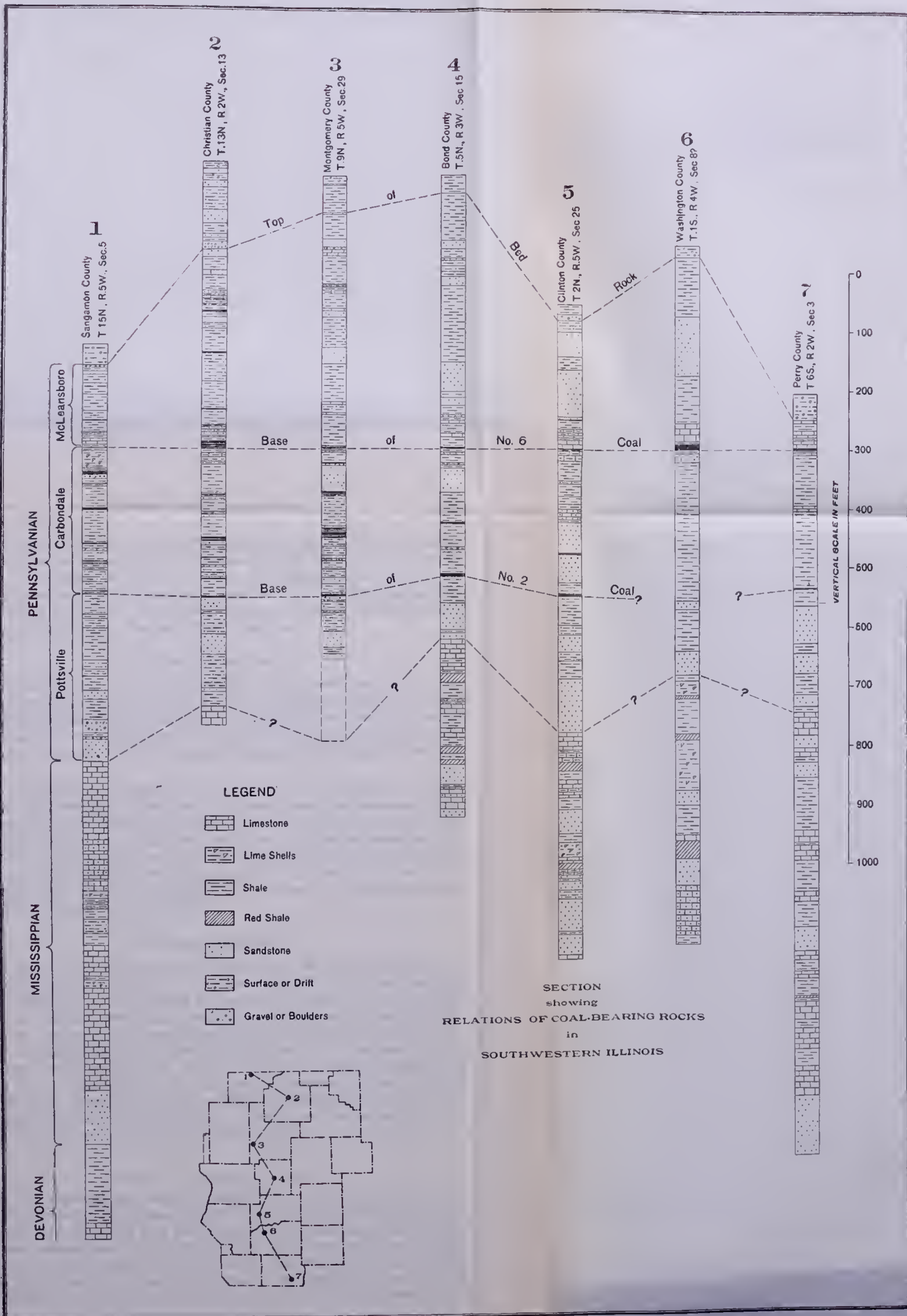
POTTSVILLE FORMATION

The lowermost formation of the Pennsylvanian in Illinois is composed chiefly of massive sandstones interrupted by thinner beds of shale and beds or pockets of coal and fire clay.

In Illinois this formation carries plant fragments which indicate, according to White,[2] that deposition took place during late Pottsville time of the Appalachian coal basins. The early sediments are thinner to the north and west and are nearly or quite absent over much of the State. Massive sandstones in the Rock Island region are of Pottsville age, but later than the first sediments of southern Illinois. There are a number of occurrences of coal in the Pottsville in southern counties but at present they have no commercial importance, because

[1]Preliminary report on organization and method of investigations, Illinois Coal Mining Investigations, pp. 48-51, 1913.

[2]White, David, Ill. State Geol. Survey Bull. 14, p. 293, 1908.



SECTION
showing
RELATIONS OF COAL-BEARING ROCKS
in
SOUTHWESTERN ILLINOIS

of local or pockety character. Coal of No. 1 of Rock Island and Mercer counties is similarly restricted in area but is thick enough to be valuable. The topmost sediments of the Pottsville in Illinois include the Cheltenham fire clays, which have been traced through the counties between St. Louis and Rock Island, and thence eastward to Ottawa. The Pottsville closed just before the deposition of coal No. 2. (Murphysboro, La Salle, Third Vein, etc.)

CARBONDALE FORMATION

The second division of the Pennsylvanian series extends from the base of coal No. 2 up to the top of coal No. 6. (Herrin, Belleville, Blue band, etc.). It represents a time interval comparable to the Allegheny formation of the eastern states, though the close of Allegheny time in Illinois has not been definitely determined and may include some of the strata lying above the Carbondale as here defined.

The Carbondale is composed chiefly of shale and lesser amounts of sandstone, coal, and limestone. It includes all the coals mined for commercial shipment except the Rock Island (No. 1) bed, and the Danville (No. 7) bed. This formation extends over practically the whole coal-area, but its upper beds are absent along the rim and its lower beds are not well known in the central part of the basin. The thickness varies considerably, being from 200 to 240 feet in the La Salle region, 200 feet at Peoria, 300 feet at Mattoon, and 285 feet or more in the southern counties of the coal field.

MCLEANSBORO FORMATION

The topmost division begins at the top of coal No. 6 and extends up to the highest Pennsylvanian rocks of the State (fig. 4). With the exception of the Danville coal (No. 7) which at present is included in this formation, there are no coals of known importance, although a thin bed in Shelby County is mined for local use. The formation is dominated by beds of shale and sandstone, among which are found some thin limestones. The Carlinville (Shoal Creek) limestone occurs about 275 feet above the base of the formation and is persistent over a considerable area. The greatest thickness of the formation seems to be in the vicinity of Hamilton and White counties where coal No. 6 lies approximately 1000 feet below the surface. A somewhat less reliable record at Olney indicates a depth of 1155 feet for this coal.

SPOON-SHAPED STRUCTURAL BASIN

The strata beneath the surface deposits of Illinois to a great extent lie horizontal, but locally dip as much as 350 feet to the mile. When all the evidence from mine shafts and bore holes is studied it is evident that the State is an immense spoon-shaped basin with the tip in the extreme northwest counties and the bowl in the region of Wayne, Edwards, Hamilton, and White counties. The long axis of the "spoon" passes near Olney in Richland County and Lovington in Moultrie County, and the dip in the central part of the basin towards this axis is commonly as low as 10 feet per mile.

Thus, an east-west section from Springfield eastward to Cerro Gordo in Piatt County has a dip of 300 feet in 50 miles or 6 feet per mile. Similiarly, the dip eastward from Iuka in Marion County to Olney in Richland County is 400 feet in 40 miles or 10 feet per mile.

The warping of the strata along the southwestern and southern rim of the basin has been much more pronounced and has been somewhat relieved by the Shawneetown fault, which extends as a narrow belt from western Kentucky into Illinois at Shawneetown and has been traced at least 15 miles farther west. This fault causes the strata on the north to be about 1400 feet lower than those on the south. North of the fault and along the border of the active coal field, the dip from Cottage Grove in Saline County northward to Eldorado averages 115 feet per mile. Similarly from Marion northward to West Frankfort it averages 50 feet per mile and locally is double this amount. In the hills 5 miles

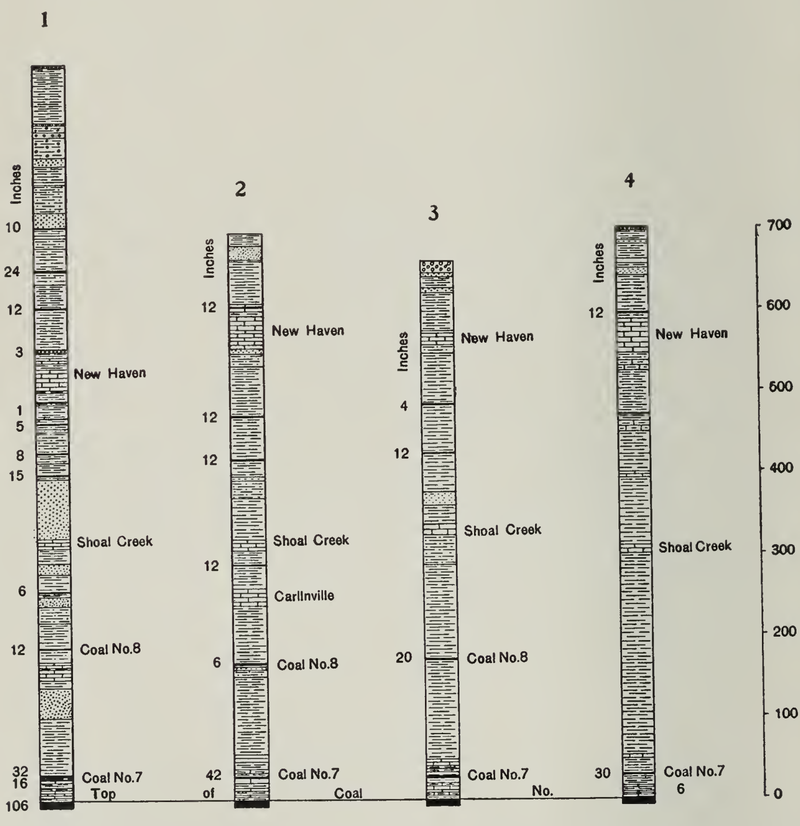


Fig. 4.—Graphic sections showing persistent nature of limestones in the McLeansboro formation.

northwest of Murphysboro the dip is eastward at a rate of 350 feet per mile. The same pitch exists also in the area one mile east of Duquoin.

Although the Illinois basin is approximately spoon shaped, there are minor folds and terrace-like flats on the flanks. The most notable is the La Salle anticline, which is pronounced at La Salle and also in the oil fields of Clark, Crawford, and Lawrence counties. Doubtless it extends as a persistent feature with a rather uniform direction between these distant areas. The west side, facing

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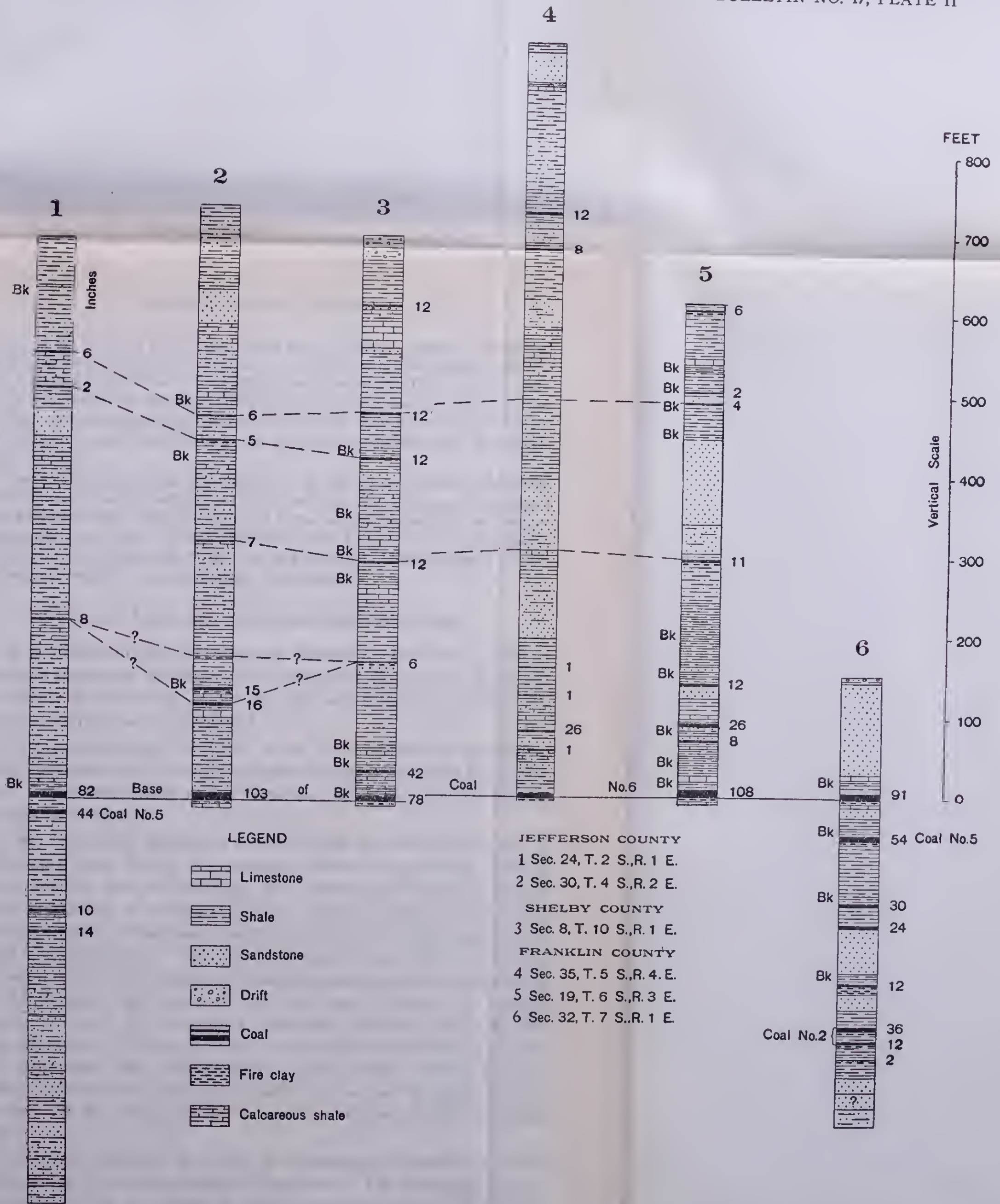


Graphic sections of borings showing the general character of the McLeansboro formation in District VI and Shelby County the axis of the basin, is much steeper than the east flank. Another pronounced anticline has been traced from the region 5 miles west of Murphysboro to Duquoin and thence northward to Centralia and Sandoval. This Duquoin anticline is also steeper on the side facing the axis of the basin, in this case the east side. Folds and faults of appreciable size other than those mentioned have been discovered, and doubtless they will be found to be numerous, as detailed surveys proceed.

The structural relations in Illinois are on the whole unusually favorable to coal mining. The first effect is of course to make the coal around the border of the field more easily available than that in the deeper portion, but the extreme depth necessary to reach the most important coal (No. 6, Herrin, Blue band) probably will not greatly exceed 1000 feet, and the shaft at Assumption is already operating successfully to approximately this depth.

Strata Associated with Illinois Coal Beds

It is important that attention be directed to the thick strata of limestone, shale, and sandstone, which lie above the various important coal seams, as these may affect the rate and amount of subsidence when underlying seams are mined.[3]

As previously noted coal No. 1 lies in the Pottsville formation, but the important beds of sandstone and of conglomerate lie below this seam. The Illinois strata in the Pottsville above this seam are largely fire clays and shales.

The Carbondale formation extends from the base of coal No. 2 to the top of coal No. 6. In northern Illinois the boundary between the Carbondale and the overlying McLeansboro formation is not as clearly marked as in southern Illinois. The Carbondale formation in southern Illinois is composed chiefly of shale but includes some sandstones and limestones. The thickness varies from 200 to 300 feet. In several typical bore holes, both limestones and sandstones are shown, but the thickest single beds of each are about 8 feet. In Jackson County, however, the Vergennes sandstone lies from 20 to 40 feet above coal No. 2. This is persistent but irregular in thickness (15 to 45 feet) and varies from a sandstone to a sandy shale. It has been described as micaceous, loose, and friable and can not be regarded as a bed that will be strong enough to check subsidence of the overlying beds.[4]

Overlying coal No. 6 is the McLeansboro formation in which only coal No. 7 is of commercial importance. The following beds of this formation are reasonably persistent, whereas some of their intervening beds vary greatly in character.

[3]For detailed reports on the geology of the districts see the Cooperative Bulletins Nos. 10, 11, 14, and 15.

[4]Shaw, E. W. and Savage, T. E., U. S. Geol. Survey Geol. Atlas Murphysboro-Herrin folio (No. 185), p. 7, 1912.

The well-marked lithologic units of the McLeansboro (in District VII) may be enumerated as follows[5]:

5. New Haven limestone, 200 to 250 feet above Carlinville limestone (thickness about 25 feet).
4. Shoal Creek limestone, about 100 feet above the Carlinville (thickness 12 to 25 feet).
3. Carlinville limestone, from 200 feet to a little more than 300 feet above coal No. 6 (average thickness 7 feet).
2. A bed of pink, red, or variegated shale, variable in thickness, averaging 35 to 50 feet above coal No. 6 (seldom exceeds 15 feet in thickness).
1. A hard limestone overlying or slightly above coal No. 6 (averages 7 feet in thickness).

The New Haven limestone is quite persistent, as indicated graphically in the records from Moultrie, Shelby, Montgomery, and Fayette counties in District VII. Mr. G. H. Cady reports it is present over parts of Franklin County from 500 to 550 feet above coal No. 6. It is a solid bed given in most logs as 25 feet thick.

The Shoal Creek limestone is from 12 to 25 feet thick and lies 275 to 350 feet above coal No. 6 in District VII. It is described as lacking the homogeneity of the Carlinville and in places consists of a series of more or less argillaceous limestone layers.[6] This limestone apparently does not occur continuously over District VI.

"The Carlinville limestone is one of the most widely distributed in the 'Coal Measures' of Illinois. It has been traced from north of Carlinville, Macoupin County, southeast to the Indiana line in Gallatin County. In the type localities this limestone is, according to Udden, 'generally bluish gray, compact, close textured, and very hard, breaking into irregular, splintery pieces. It averages about seven feet in thickness'. In most of District VII the interval between this limestone and coal No. 6 averages from 275 to 325 feet."[7] In District VI this stratum occurs from 250 to 300 feet above coal No. 6 but is thin and has not been mentioned in many of the records.[8]

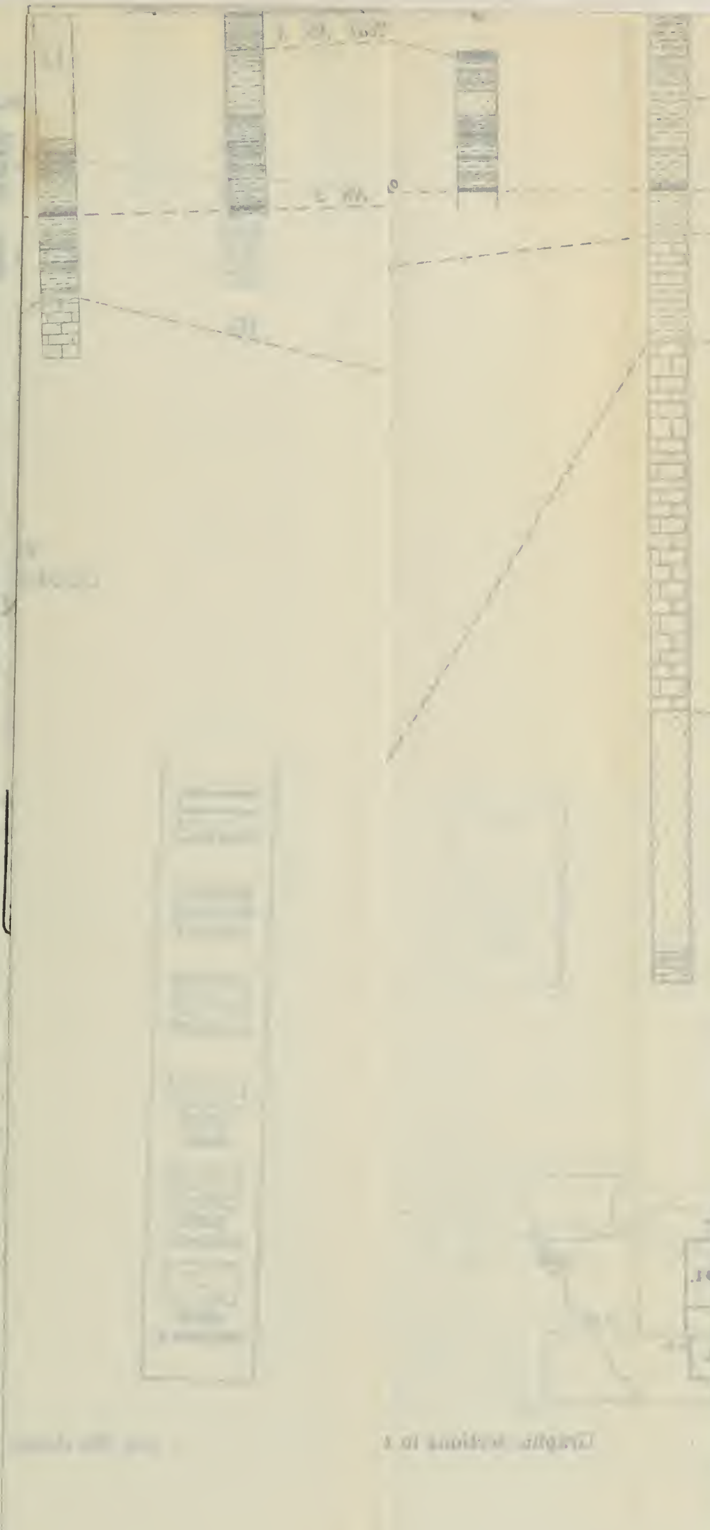
In parts of Saline and Gallatin counties there occurs a hard sandstone, known locally as "Anvil Rock", a sandstone about 10 feet above coal No. 6. In several of the small mines on coal No. 6 in Gallatin

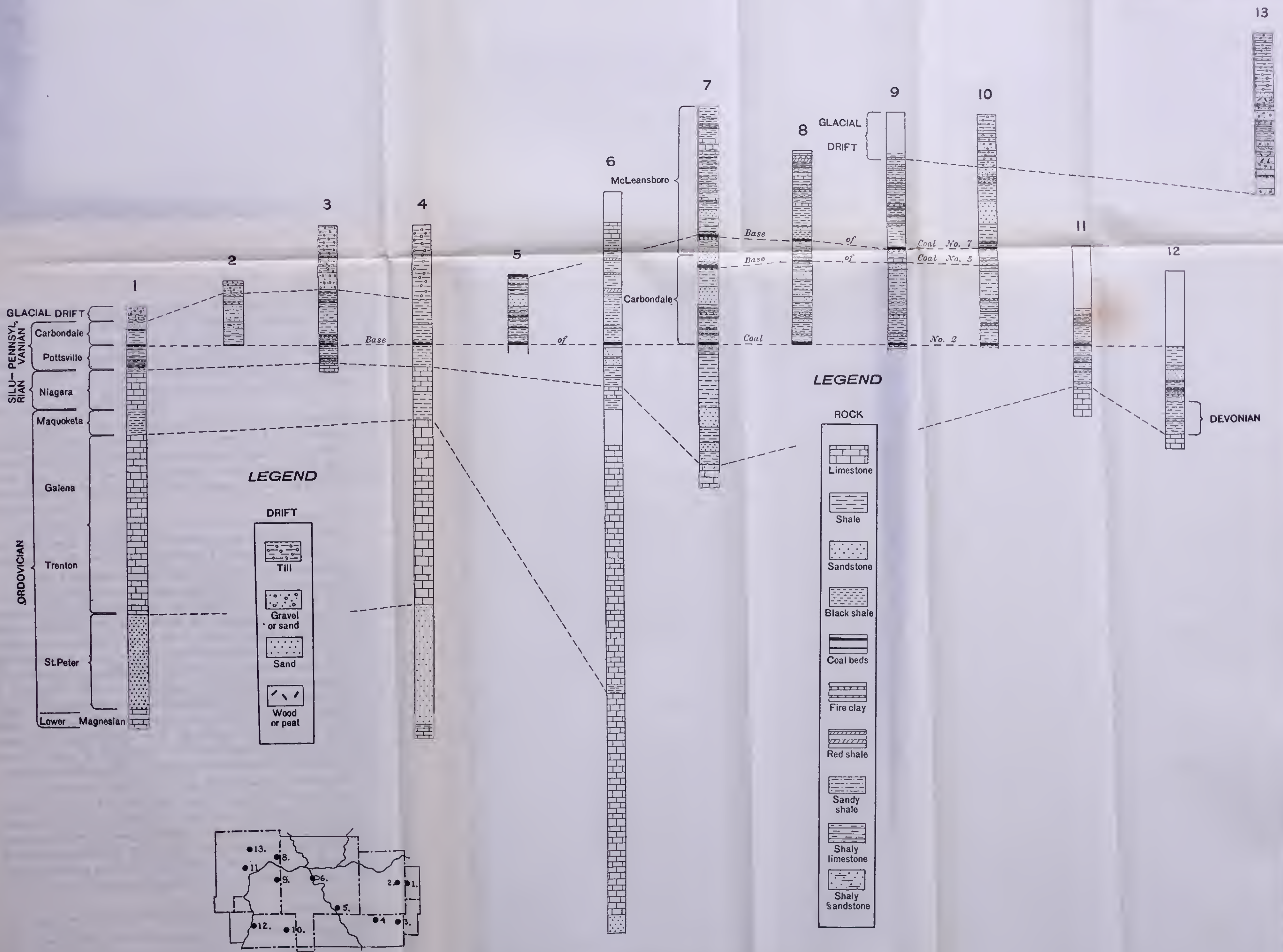
[5]Kay, Fred H., Coal resources of District VII: Ill. Coal Mining Investigations Bull. 11, p. 23, 1915.

[6]Lee, Wallace, acknowledgements to, Illinois Coal Mining Investigatons Bull. 11, p. 26, 1915.

[7]Kay, Fred H., Coal resources of District VII: Ill. Coal Mining Investigations Bull. 11, p. 25, 1915.

[8]Cady, G. H., Coal resources of District VI: Ill. Coal Mining Investigations Bull. 15, p. 34, 1916.





Graphic sections in the Longwall District. Scale: 1 inch equals 200 feet

County, it serves as the immediate roof. There the limestone lying above coal No. 6 is described as the limestone cap rock. Throughout District VII this limestone is generally not less than 2 feet thick, although in several small areas it is entirely missing. The range commonly is from 5 to 10 feet. In some places the cap rock is underlain by black "slate" or shale a few feet in thickness, and in others by a gray shale known as "white top."[9]

In District VI the cap rock occurs over a large part of the district within 25 feet above coal No. 6. It is described as a compact, heavy-bedded limestone, commonly dark or almost black when fresh. It may be as thick as 11 feet, but averages 4 or 5 feet. Over the western part of District VI the cap rock is missing, or is at a greater distance above the coal.[10]

A log given as typical of the eastern part of District VII shows, in a total depth of 658 feet 6 inches to the top of coal No. 6, a total thickness of 24 feet of limestone and 15 feet of sandstone.

In the Longwall District the strata of the Pennsylvanian series are not so persistent as in southern Illinois. Graphic sections in the Longwall District are shown on Plate III. So far as is known no single limestone stratum, except the Lonsdale limestone, is traceable from one point to another in the Longwall District, and even the Lonsdale limestone is not readily identified in drill records. It contains a large amount of argillaceous material and is easily mistaken for shale in drilling.[11] "The lower 5 feet consists of a firmly cemented, largely organic limestone in beds varying in thickness from 6 inches to 1 foot 6 inches. Above these firm beds there are 15 feet of a slightly argillaceous and more flaggy rock, in which concretionary structures can nearly always be detected."[12] It occurs near the base of the upper section of the McLeansboro formation and 50 to 75 feet above coal No. 7.

In the upper section of the McLeansboro and about 400 feet above coal No. 2 or 175 feet above coal No. 7 occurs the La Salle limestone, varying from 25 to 30 feet in thickness. "It has a very local distribution, being confined to a belt about two miles broad and extending parallel to its outcrop along the anticline from Bailey Falls on the south to the NE. ¼ sec. 28, T. 34 N., R. 1 E., three miles north of La Salle. The belt is much wider in the middle than at either end.

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[9]Kay, Fred H., Coal resources of District VII: Ill. Coal Mining Investigations Bull. 11, p. 24, 1915.

[10]Cady, G. H., Coal resources of District VI: Ill. Coal Mining Investigations Bull. 15, p. 30, 1916.

[11]Cady, G. H., Coal resources of District I: Ill. Coal Mining Investigations Bull. 10, p. 41, 1915.

[12]Udden, J. A., Geology of the Peoria quadrangle, Illinois: U. S. Geol. Survey Bull. 506, p. 39, 1912.

The same horizon extends farther westward, but the lithological change is considerable.[13] The extent to which these beds affect subsidence in the Longwall District has not been determined.

From the foregoing it seems that there are few, if any, persistent beds that are hard enough and thick enough over large areas to influence greatly the problem of subsidence.

By the Cooperative Coal Mining Investigations the State has been divided into districts as shown in figure 49. In the following tabulation of notes on roof and floor, the data submitted in the reports upon the several districts are used together with such supplemental data as have been secured later.

TABLE 3.—*Character of roof and floor of the commercial coal beds throughout Illinois*

Coal No. 1

Districts and counties	Roof	Floor
III	In Mercer and Rock Island counties, hard black shale 2 to 5 inches thick; limestone cap rock, 1 to 4 feet.	Light gray micaceous fire clay which heaves badly when wet. In places an irregular band (3 to 6 inches) of carbonaceous shale or sandstone lies immediately below the coal.

Coal No. 2

I	Gray shale, replaced in places by a black shale about 3 feet thick.	Dark-gray fire clay up to several feet thick. In some parts of the La Salle field a hard sandstone lies directly beneath the coal.
II	Gray shale up to 36 feet thick. In some places, dark-colored shale which is hard to support.	Bottom bench of coal is a layer of bone 2 to 3 inches thick. In most places floor is sandstone; in sections is shale or fire clay.
III	Hard black shale generally not over 1 foot thick, overlain by a limestone cap rock 3 feet thick.	Gray fire clay containing nodules of iron pyrites.

[13]Cady, G. H., Coal resources of District I: Ill. Coal Mining Investigations Bull. 10, pp. 36-39, 1915.

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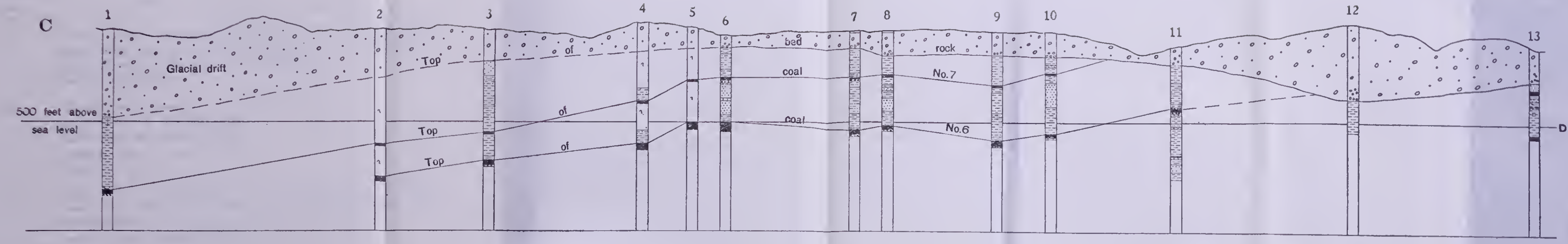

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9 Sec.30,T.18 N.,R.11 W.
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6 Sec.35,T.20 N.,R.12 W.
7 Sec.36,T.20 N.,R.12 W.
8 Sec.29,T.20 N.,R.11 W.
9 Sec.21,T.20 N.,R.11 W.
10 Sec.22,T.20 N.,R.11 W
11 Sec.14,T.20 N.,R.11 W.

LEGEND

Limestone
Shale
Clod
Sand or sandstone
Sand and shale
Drift
Black slate
Coal
Fire clay

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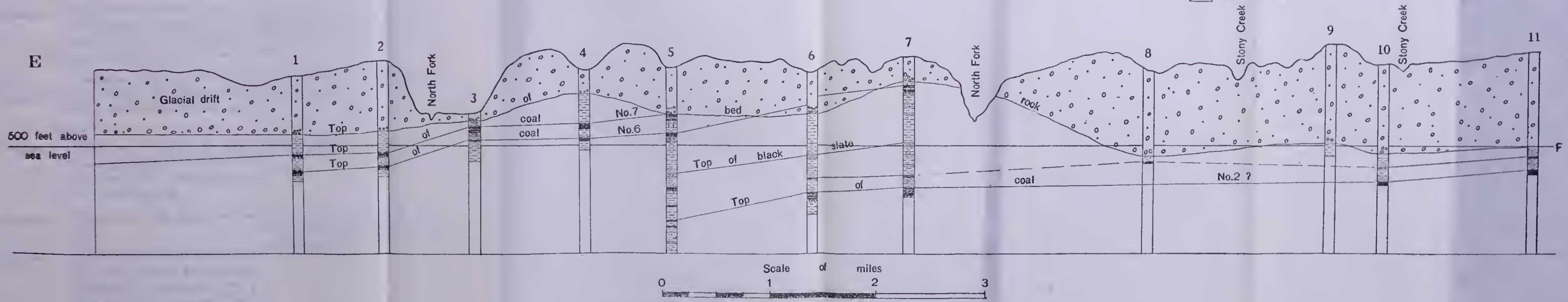

Cross-section CD showing structure across the southern part of the Danville field
Cross-section EF showing structure across the northern part of the Danville field

Coal No. 5

Districts and counties	Roof	Floor
I	Varies from a gray shale to black "slate", sandstone and locally limestone; "white top" roof in certain areas.	Gray fire clay 1 to 4 feet thick, underlain by sandstone or sandy shale.
IV	Black sheety shale up to 35 feet thick. A limestone cap rock over the shale. Where shale is thin, the cap rock becomes the roof.	Gray fire clay.
V	Light gray to black shale, in some areas laminated with coal for a distance of 3 feet above seam. Shale of immediate roof is weak.	Fire clay generally. In some areas the clay is sandy and heaves badly when wet.

Coal No. 6

Districts and counties	Roof	Floor
VI *Franklin*	Coal is left as immediate roof. Upon the coal is a thin bed of draw slate, and within 25 feet above the coal is usually a limestone cap rock 4 to 10 feet thick.	Gray fire clay 2 to 8 feet thick underlain by a sandy limestone. Heaves in only a few mines.
Williamson	Coal is left generally as roof. In a number of mines the limestone cap rock is missing or higher than in Franklin County.	Gray fire clay 2 to 4 feet thick underlain by limestone. The floor heaves badly in several mines.
VII *Clinton*	Limestone cap rock, 5 to 15 feet thick. In places black shale between limestone and coal.	Clay, 18 inches to 8 feet in most places on shale.
Christian	Black shale overlain by limestone ranging from 1 to 20 feet. In some mines shale between coal and limestone.	Clay of variable thickness.
Macoupin	Black shale with limestone cap rock.	Clay averaging about 1 foot. Beneath the clay there is generally limestone.
Madison	Gray or black shale of varying thickness overlain by limestone ranging in thickness from a few feet to as much as 30 feet. In some places limestone rests on the coal.	

Table 3.—*Character of roof and floor of the commercial coal beds throughout Illinois*—Concluded

Coal No. 6—Concluded

Districts and counties	Roof	Floor
Marion	Limestone cap rock, about 15 feet thick.	Clay of varying thickness.
Montgomery	Limestone cap rock.	Clay of variable thickness.
St. Clair	Black shale and limestone.	Thin clay on limestone.
Perry, Randolph, and Washington	Black shale under limestone to the west of Duquoin anticline. To the east, the same limestone is 100 feet above coal.	Clay of variable thickness.
Shelby and Moultrie	Shale and limestone.	Shale, clay, limestone.
Sangamon	Irregular shale and limestone.	Thin clay.
VIII	Roof is variable. Immediate roof generally a grayish-black shale about 6 feet thick. Difficult to support in many areas. Many irregularities.	Generally a grayish fire clay varying in thickness up to several feet. Heaves badly when wet. A bed of limestone beneath the fire clay.

Coal No. 7

Districts and counties	Roof	Floor
I	Gray silicious shale 35 or more feet thick. Immediate roof is generally darker than the upper beds of shale.	Gray fire clay 2 to 3 feet thick lying on sandstone. Black shale in places forms the floor.
VIII	Black shale up to several feet thick under a gray shale as much as 50 feet thick in places.	Immediate floor is a thin bed of clay which heaves badly. Beneath is a layer of harder clay 5 to 15 feet thick. Some streaks of coal in the clay.

Cleat

It has been suggested by some mine operators that subsidence may be avoided if in room-and-pillar mines the rooms are driven face on the cleat. The theory is that the immediate roof and the overlying strata are jointed in the same direction as the cleat, and that most of the slips occurring in the roof also run in the direction of the cleat. It is held that if the rooms are properly turned, the pillars will catch up these slips and prevent any local movement which may be the beginning of a general movement causing subsidence.

At the present time there are not sufficient data collected to prove or disprove this statement. At several mines where attention is paid to the cleat no subsidence has occurred, but there are a number of mines with rooms opened on the cleat in which serious subsidence has resulted.

Faults and Rolls

GENERAL RELATIONS TO SUBSIDENCE

As will be noted later, the movement of the overlying beds following the mining of coal may be influenced greatly by both the character and structure of the beds themselves. If faults occur, the ability of beds to arch and thus to support the surface may be destroyed. Moreover, the effects of subsidence may be localized if faults are numerous, for the faulted beds over the mined-out area will fall in blocks and will not produce long sags with the usual draw or pull.

In almost all the districts of the State faults, slips, and rolls would interfere more or less with the application of formulae and theories of subsidence. In certain districts, as will be noted, these irregularities are much more marked. Moreover, the occurrence of slips, rolls, horses, and of other irregularities in the coal bed itself increases the amount of barren material thrown into the gob and thereby the amount of filling is increased and the amount of subsidence may be reduced. When the rolls or horses are not broken by mining they serve as pillars and help support the overlying strata if slips do not occur along the line of the rolls or horses.

COAL NO. 2

District I.—The geologists report no important faults, but numerous small displacements have been noted in the coal seam. Both thrust and normal faults have been noted (see figures 18, 19, 20, Bull. 10, Illinois Coal Mining Investigations). At many points the coal is thinner and the roof rolls down.

District II.—"In all the mines of this district numerous small faults occur, and horses usually of a hard dark-gray, micaceous sandstone are found in the vicinity of the faults."[14]

COAL NO. 5

District I.—"A peculiar condition of the roof and coal known locally as 'white top,' exists on the west side of the M. & H. mine (see figure 21, Bull. 10, Ill. Coal Mining Investigations) on the east side of the Cherry mine (middle bed), and, according to report, in the Cahill mine. At Cherry this consists of a white to gray sandstone or

[14]Andros, S. O., Coal mining practice in District II: Illinois Coal Mining Investigations Bull. 7, p. 10, 1914.

sandy, gray shale which replaces the usual gray and black shale of the roof and permeates the coal down to a band of clay found about 14 inches from the floor. Large pieces of white sandstone are found scattered through the bed so that the whole resembles a conglomerate. Slickenside surfaces are common throughout the 'white top' areas, and the roof is commonly rough and broken, so that it is very difficult to keep the roads clear. The impurities at some of these places exceed one-half of the total thickness of the bed, and render the coal worthless."[15]

District IV.—Numerous clay veins extend from the roof across the coal seam.[16] There are also many small faults, slips, and rolls. Mr. J. A. Udden[17] has applied the term "fractures" to the dislocations occurring in the Peoria district. These fractures "are believed to be the result of physical processes altogether different from those causing faults. In many places they have a close resemblance to true faults, but the direction of the dislocation is normally horizontal instead of normally vertical."[18]

In the Springfield region numerous so-called "horsebacks" occur. "These are more or less irregular and branching fissures, filled with clay or shale, extending downward from the overlying beds into or through the coal. They range in width from 2 or 3 inches to 3 or 4 feet, the walls not being very nearly parallel, and are considerably and abruptly wider in the coal than in the overlying roof shale."[19]

District V.—Coal No. 5 is faulted at a number of places in the district and contains many rolls. In several places an igneous intrusive penetrates the coal bed and in others it lies in a sheet at some distance above the coal. Squeezes and subsidence have undoubtedly been influenced greatly by these irregularities in this district. Detailed records of subsidence adjacent to faults and dikes are given in Chapter V.

COAL NO. 6

District VI.—Reference has previously been made to the cap rock in this district. In some places there are rock rolls extending down into the coal. Minor faults occur, but they do not interfere with

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[15]Cady, G. H., Coal resources of District I: Ill. Coal Mining Investigations Bull. 10, p. 78, 1915.

[16]Andros, S. O., Coal mining practice in District IV: Illinois Coal Mining Investigations, Bull. 12, fig. 4, 1915.

[17]Udden, J. A., Geology and mineral resources of the Peoria quadrangle, Illinois: U. S. Geol. Survey Bull. 506, p. 68, 1912.

[18]Andros, S. O., Coal mining practice in District IV: Illinois Coal Mining Investigations Bull. 12, fig. 5, 1915.

[19]Shaw, E. W. and Savage, T. E., U. S. Geol. Survey Geol. Atlas, Tallula-Springfield folio (No. 188), p. 3, 1913.

mining to a large degree. A detailed statement of faults in the district is given in the bulletin on the geology of the district.[20]

District VII.—Minor faults or slips in coal No. 6 seam have been noted in Clinton, Macoupin, Madison, Marion, Montgomery, St. Clair, Perry, Randolph, Washington, and Sangamon counties. North of Centralia the so-called "Centralia fault" has a displacement of 110 feet. East of the Duquoin anticline numerous small faults occur, the largest having a downthrow of 20 feet.[21]

District VIII.—There are numerous rolls in coal No. 6 in the Danville region. Stringers and lenses of shale extend down from the roof into the coal. In places there are minor faults. A detailed study of the irregularities in the coal bed has been made by Mr. F. H. Kay.[22]

COAL NO. 7

District I.—Coal No. 7 is quite irregular and contains horsebacks and rolls which add considerably to the volume of material thrown into the worked-out rooms.[23]

District VIII.—Numerous horsebacks or rolls occur in this bed in the Danville district but they are not so extensive as in coal No. 6.[24]

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[20]Cady, G. H., Coal resources of District VI: Illinois Coal Mining Investigations Bull. 15, pp. 82-87, 1916.

[21]Kay, F. H., Coal resources of District VII: Illinois Coal Mining Investigation Bull. 11, pp. 196 and 197, 1915.

[22]Kay, F. H., Coal resources of District VIII: Illinois Coal Mining Investigations Bull. 14, pp. 42-49, 1915.

[23]Cady, G. H., Coal resources of District I: Illinois Coal Mining Investigations Bull. 10, p. 85, 1915.

[24]Kay, F. H., Coal resources of District VIII: Illinois Coal Mining Investigations Bull. 14, p. 53, 1915.

CHAPTER III—DAMAGE CAUSED BY REMOVAL OF COAL

Contrasting Effects of Longwall and Room-and-Pillar Methods

It may be said that in general the surface effects of longwall mining are more uniform than those resulting from room-and-pillar and panel working. This is due principally to the gradual sinking of the roof in longwall mining where the same gradual movement generally extends through the overlying rocks toward the surface. Upon the surface the evidences of subsidence will be a gentle sag, and where the longwall face is stopped there may be a more or less well-defined terrace outlining in a general way the area that has been undermined. Except in a shallow working and in faulted areas probably no large surface cracks or breaks will occur, and if these do occur they will usually close after the longwall face has advanced some distance beyond the point in the mine vertically below.

On the other hand, where coal has been mined by other systems, the area over which the settling may extend is generally smaller, and serious cracks and breaks are more likely to result.

Surface Evidences of Subsidence

In general, it may be said that the principal ways in which surface movement is shown are by: (1) surface cracks and displacements, (2) pit holes or caves, and (3) sags. The sags and holes frequently hold accumulations of surface water.

surface cracks and displacements

As previously noted, serious cracks have not been observed frequently in the longwall district of Illinois. One of the reasons that no surface cracks are evident is the presence of a heavy blanket of glacial drift from 25 to 200 feet thick lying over the "Coal Measures" in this district. At various points where the workings have been shallow, the rock cover thin, and the surficial beds saturated with water, serious breaks have resulted accompanied by a rush of sand, mud, and water into the mine. The resulting break upon the surface is however not typical of longwall mining, and this type of break is as likely to occur in room-and-pillar mining. In Europe at various points in the longwall coal mining districts, cracks several inches wide have been observed above longwall workings over 1,000 feet deep.

The surface cracks that have been observed have been due to tension and to shear. Where the coal has been removed over a large area in room-and-pillar mining, the roof if unsupported sinks gradually, and if it does not break will in time rest upon the floor. In longwall mining, the roof settles upon the gob and compresses it so that in time it occupies a volume equal to only a small fraction of the volume of

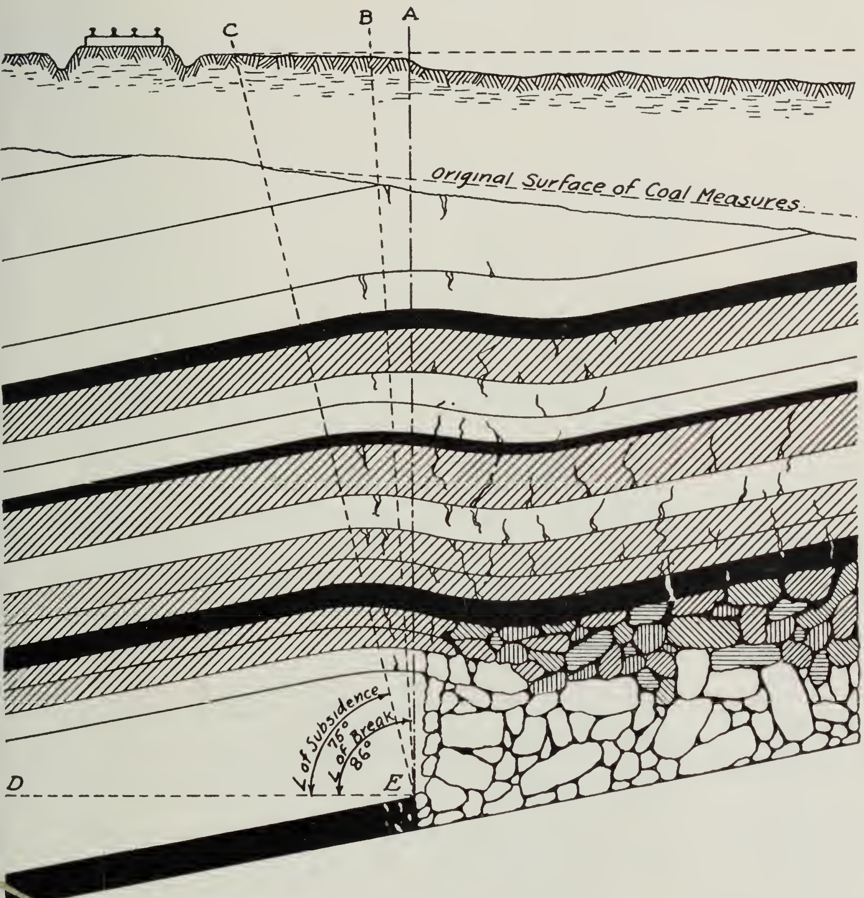

Fig. 5.—Diagrammatic illustration showing angle of break and angle of subsidence (after Wachsmann).

the excavation, depending upon the nature and the amount of the filling. As the immediate roof sinks the overlying beds also sink, and stresses are set up in the various beds successively from the immediate roof to the surface rocks (fig. 5). If each stratum is regarded as a beam, a portion of the beam will be in tension and a portion in compression. As the ordinary rock of mine roofs is much weaker in tension than in compression, cracks due to tension will appear before the evidences of compression. Tension cracks may be found in the mine roof in the zone where tension is greater than the tensile strength of the rocks, and similarly, upon the surface tension cracks may be found in the rocks or in consolidated surficial beds in the tension zone. Where there has been an extensive sag over a worked-out area, tension cracks are likely to occur around the perimeter of the sag. Figure 6 shows a tension crack from 4 to 10 inches wide occurring over a room-and-pillar mine in the Streator district.

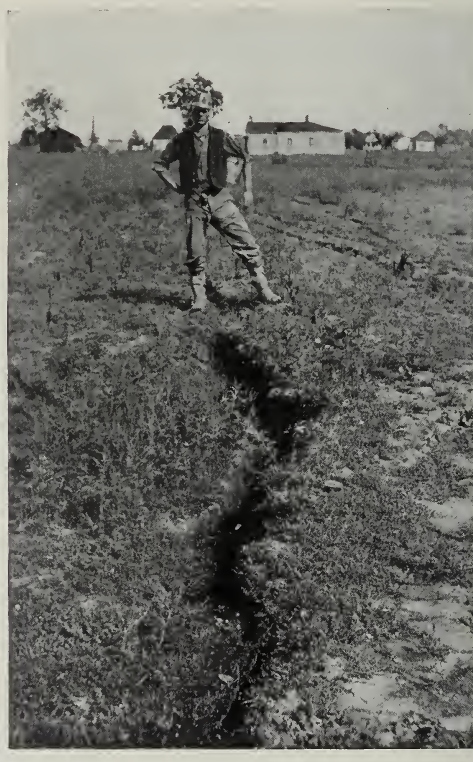

Fig. 6.—Crack in the soil, caused by room-and-pillar mining at a shallow depth at Streator.

In a mine on coal No. 6 in Franklin County a number of squeezes have resulted in surface subsidence. The shaft is 550 feet deep and the coal 9 to 10 feet thick, from 1 to 2 feet being left as roof coal. The mine is worked in panels, room centers being 40 feet and pillars 18 feet (fig. 7). No pillars have been drawn. In two panels there has been movement which has affected the surface. At "A" the crack is 8 to 10 inches wide and at "B" there are two cracks, one of which is 2 to 3 inches wide (figs. 8 and 9).

Where the mine roof fails by shear along the pillars or supports, the entire overlying mass may be dropped into the excavation, and a more or less sharp break may appear on the surface. Where the fallen mass is large, a series of breaks may occur, as shown in figure 10. In the opinion of a number of prominent American engineers the strata above the immediate roof frequently fail by shear.

As previously noted the mine roof is likely to fail first in tension, and readjustment is likely to precede failure under compression. If

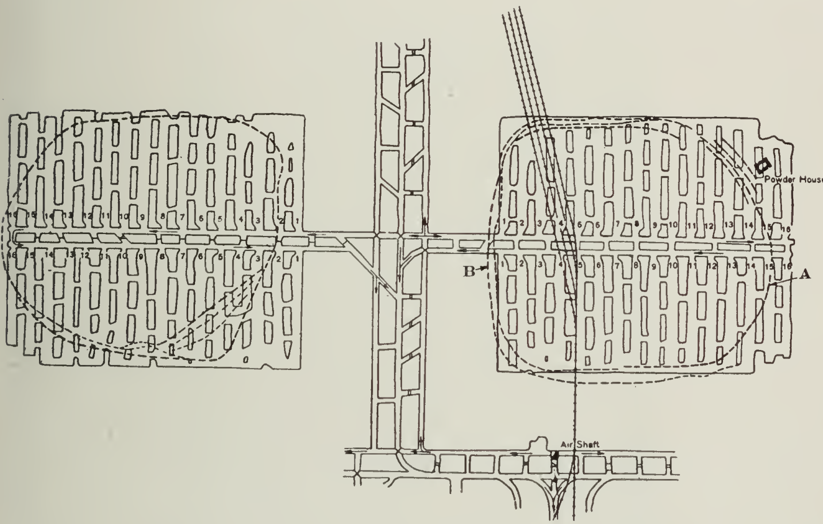

Fig. 7.—Plan of two panels of a Franklin County mine, 550 feet deep. Subsidence caused surface cracks as indicated. Over the north panel at A the crack was 8 to 10 inches wide, and at B were two smaller cracks.

great lateral pressure and a free or unconfined surface exist, buckling may result, as illustrated in the heaving of the rock floor in deep mines and tunnels. One of the best illustrations of this type of movement occurred in the Simplon tunnel in Europe.[1]

Where there is a sag over an extensive area or subsidence over an excavation of considerable height, the surface of the central position of the basin may be subjected to severe stresses in compression. This will result in the elevation of this central area relative to the adjacent portion of the subsiding ground, although the entire mass may be sinking. If the uppermost stratum is rock or hard material, such as frozen

[1]Lauchli, E., Tunneling, fig. 92, p. 95, 1915.

soil, this compression may result in buckling, and small anticlines may result, as shown in figure 11.

PIT HOLES OR CAVES

Where shallow mining is carried on, falls of mine roof are frequently followed by surface subsidence causing pit holes or caves.

Fig. 8.—Crack, 8 to 10 inches wide, due to subsidence over the north panel shown in figure 7. The view was taken from A looking west. (Photo by J. R. Fleming, U. S. Bureau of Mines.)

If the rock cover is not thick and the surficial beds are heavy and loose, the mine openings may be filled by a rush of surficial material, so that the pit hole may have a much greater volume than the single mine chamber in which the break occurred. Such pit holes may appear directly over many worked-out rooms and may destroy entirely the value of the surface for agriculture and for building sites. When subsidence has ceased, the surface may be restored by filling. Pit holes of various types are illustrated in figures 12 to 18.

When the surface beds are cemented material, frequently called "hard pan," an arch may tend to form across from one pillar or wall to another. Falls may extend close to the surface and be concealed

FIG. 9.—Cracks over south side of panel shown in figure 7. The view was taken from B looking east. (Photo by J. R. Fleming, U. S. Bureau of Mines.)

by a thin covering of a resistant bed. Eventually this last bed may break, and the fall may show the large cave beneath, as illustrated by figure 19. Where the soil is covered by a heavy sod, the dangerous condition of the fields may be concealed for a time owing to the tenacity of the sod. Heavy sheets of sod may be seen (fig. 20) hanging over the rim of breaks, and instances have been reported in which for a considerable time simply a sod roof has concealed caves several feet in diameter.

Fig. 10.—Cracks and breaks due to shear. View along the rim of a large pit hole caused by an extensive movement into a shallow mine. In the right foreground the mass of earth has dropped 18 inches.

Fig. 11.—Buckling of frozen sod due to compression along the axis of a basin or sag. The movement occurred over a large excavation in a shallow mine. The sod in the foreground was lifted as much as two feet.

FIG. 12.—Surface breaks in a field near Carterville. The shaft is 120 feet deep, and a 7-foot bed of coal is being mined. The roof is slate and the overburden clay; no quicksand has been noted. The breaks are about 20 feet in diameter and from a few feet to as much as 20 feet deep.

FIG. 13.—Surface breaks extending over a room in a mine near Harrisburg where the coal is 7 feet thick and 80 feet deep. The rooms are 24 feet wide and have 24-foot pillars.

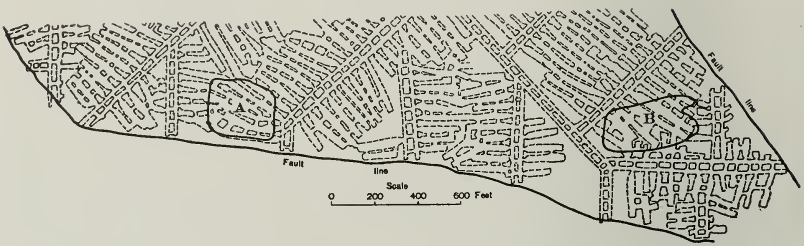

FIG. 14.—Plan showing workings of a mine and location of subsidence movements adjacent to a dike.

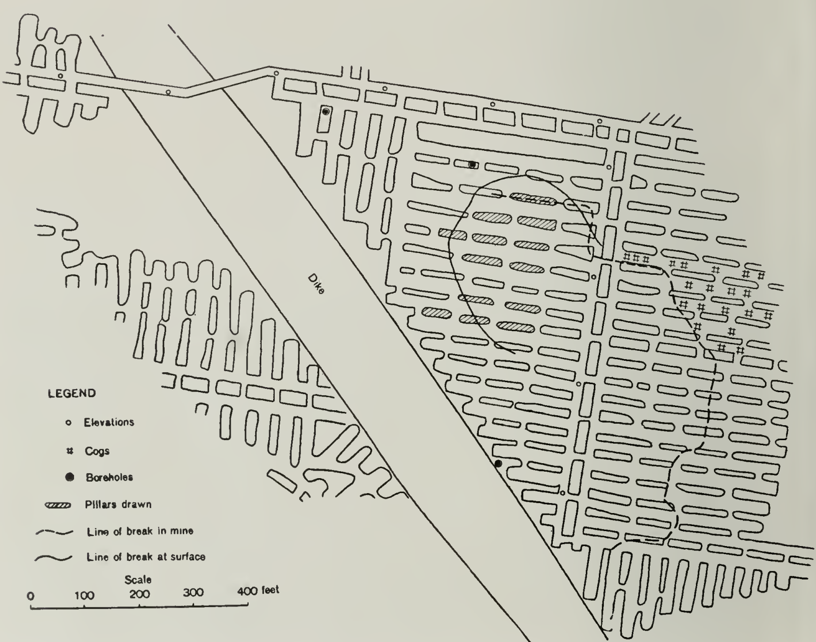

FIG. 15.—Plan of a mine showing a few details of movement near a dike.

FIG. 16.—Breaks in a pasture over an abandoned mine west of Danville where the coal is 6 feet thick and 100 feet deep.

FIG. 17.—Side-hill breaks near Cuba caused by room-and-pillar mining of a 5-foot bed of coal from 50 to 75 feet deep.

FIG. 18.—Large area covered by pit holes in the suburbs of a town in central Illinois where a 5-foot bed of coal is being mined at a depth of 75 to 100 feet. Trees are falling into the pit holes; the houses are being used.

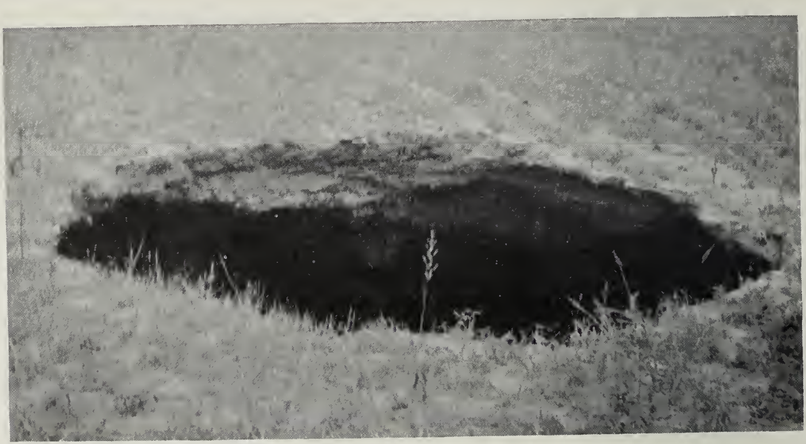

FIG. 19.—Cave-in on land south of Dewmaine where a 9-foot bed of coal is being mined at a depth of 100 feet. The opening is 12 feet in diameter and 15 feet below the surface; the width is approximately 25 feet. The hard pan arches up from the shale.

Where the breaks occur on hillsides, a series of resulting movements may be due to the natural slope of the ground. The more or less concentric rings formed by these breaks are shown in figure 21.

Fig. 20.—Detail of a cave on a hillside near Streator; note the hanging sod.

A serious condition is illustrated in figure 22 where the surface is owned by one mining company as a site for company houses, and the coal is owned and mined by another company. The owner of the coal is reported to be mining from 8 to 11 feet of coal at a depth of 100

Fig. 21.—Side-hill breaks over shallow workings near Streator.

feet by the room-and-pillar method. The owner of the surface secured an injunction restraining the mining of coal under the buildings shown in the illustration. The court would not restrain mining under the other portions of the tract as any damage resulting might be the basis for a suit.

SAGS

Where the workings are covered by thicker and stronger beds of rock, and the area excavated is larger, the surface effects of subsidence may be sags instead of breaks, caves, or pit holes. During part of the

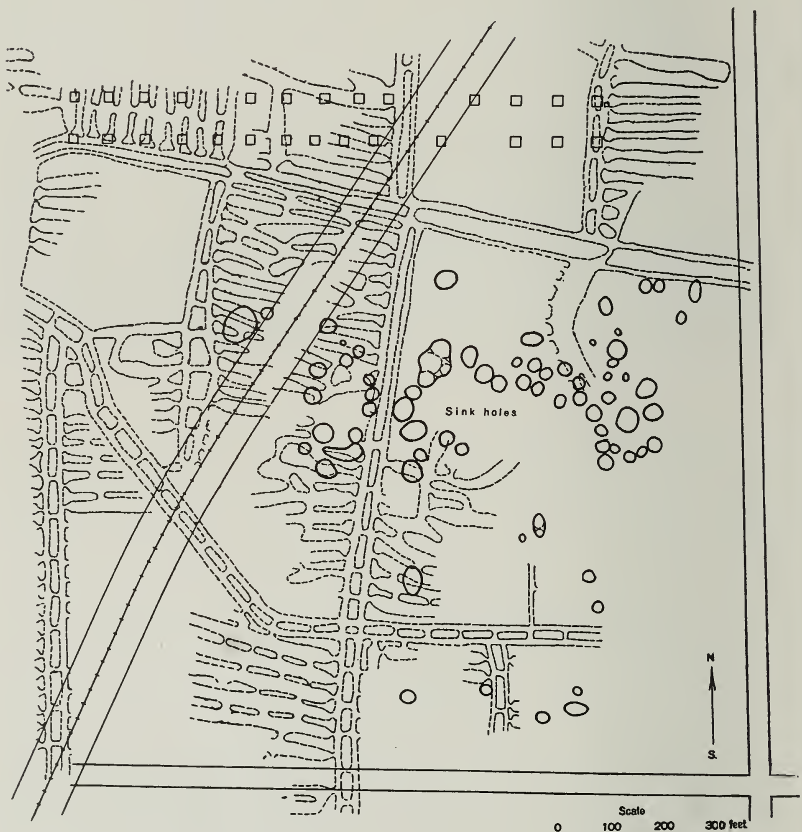

FIG. 22.—Plan of a 40-acre tract in southern Illinois, showing relation of approximately 60 pit holes to the underground workings.

year these sags may contain pools of water, and if they are considerably below the previous drainage levels, they may be inundated continually.

In the longwall field of northern Illinois it is necessary to provide artificial drainage for much of the land which is otherwise suited for agricultural purposes. Figure 23 shows the nature of the topography in the Coal City-Wilmington area. It is evident that subsidence resulting from mining operations may seriously derange the artificial drainage systems which are installed. Figure 24 shows a pond formed over a sag due to longwall mining near Coal City.

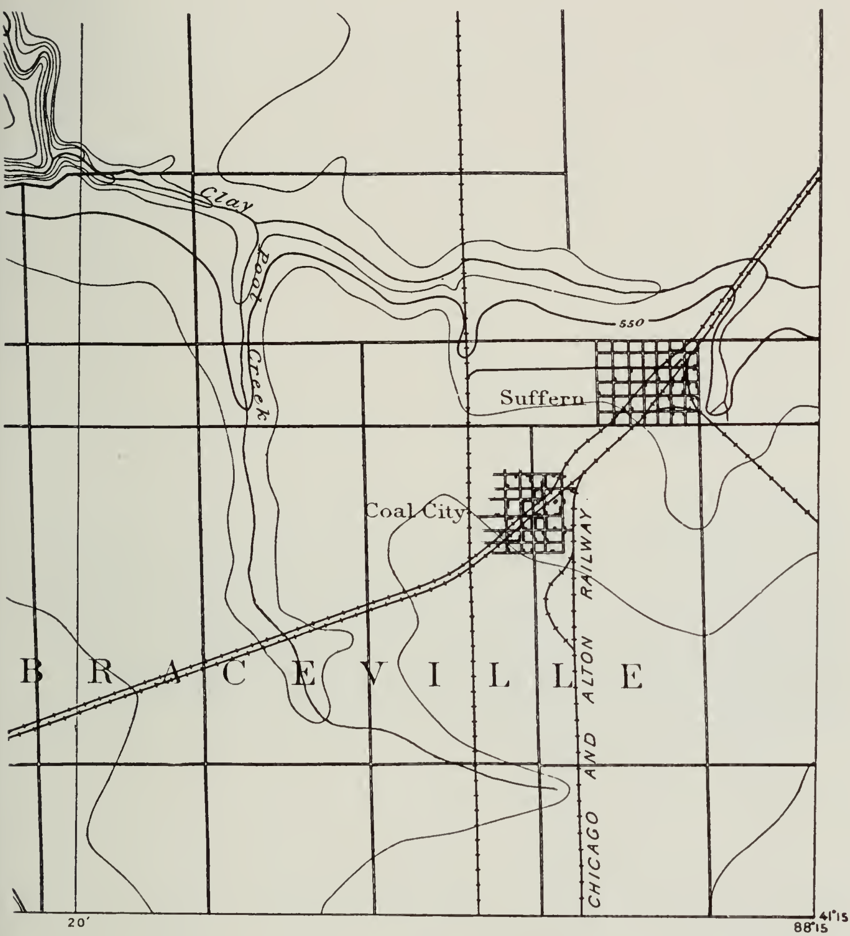

FIG. 23.—Topographic map of the Coal City-Wilmington area.

In a portion of a mine in Perry County (fig. 25) opened on coal No. 6 at a depth of 350 feet the coal averages 9 to 11 feet, but the upper bench of 3 feet is not mined. Six sags but no surface breaks have resulted from the mining. In general the pillars have not been drawn. In one place where pillars have been drawn an area 600 feet in diameter sagged, the maximum depression being 4 feet; the subsidence of the surface began twenty-four hours after the movement was observed underground. Another area 800 feet in diameter with a maximum depression of 3 feet was noted at the same mine.

At a mine in Franklin County where the coal seam is 9 feet thick, one foot of the top coal is left in mining. The shaft is approximately 450 feet deep. The roof is gray shale, and no limestone occurs immediately over the coal. The bottom is fire clay varying from a few inches to 5 feet. A number of squeezes have occurred, principally where the rooms have been turned on 45-foot centers with 15-foot pillars. The rooms were carried 250 feet and it was planned to leave a 20-foot barrier between panels of rooms. In places the room necks have been turned wide, and the room cross-cuts have been driven about 20 feet wide. The main entries are protected by a barrier pillar of 110 feet, the cross-entries have been driven on 25- and on 50-foot centers.

Fig. 24.—Pond in a sag due to longwall mining at Coal City, where a 3-foot bed is being removed at a depth of 135 feet.

Several squeezes had taken place where pillars had been drawn, particularly on one panel in the northeastern section of the mine. In November, 1914, an extensive movement began underground in the panel adjoining on the east a panel that had previously squeezed, and surface subsidence resulted. Mining had been completed in this panel 2 to 3 months previous. The movement continued several weeks, and a large fall occurred on the night of December 9, 1914. Falls continued for 4 hours, and the following morning there were evidences of surface movement. A railroad bridge had subsided 18 inches, concrete sidewalks cracked in some places (see figure 48) or broken by buckling in others, telephone poles were tipped (see figure 26), and foundations of houses were cracked. Later when the snow thawed, the lateral extent of the movement was evidenced by the ponds which covered a large area (see figure 46). From the data at hand no evidence showed that at the end of two weeks the depressions were more than 18 inches deep. However, at the end of three months the subsidence at places was as much as 4 feet.

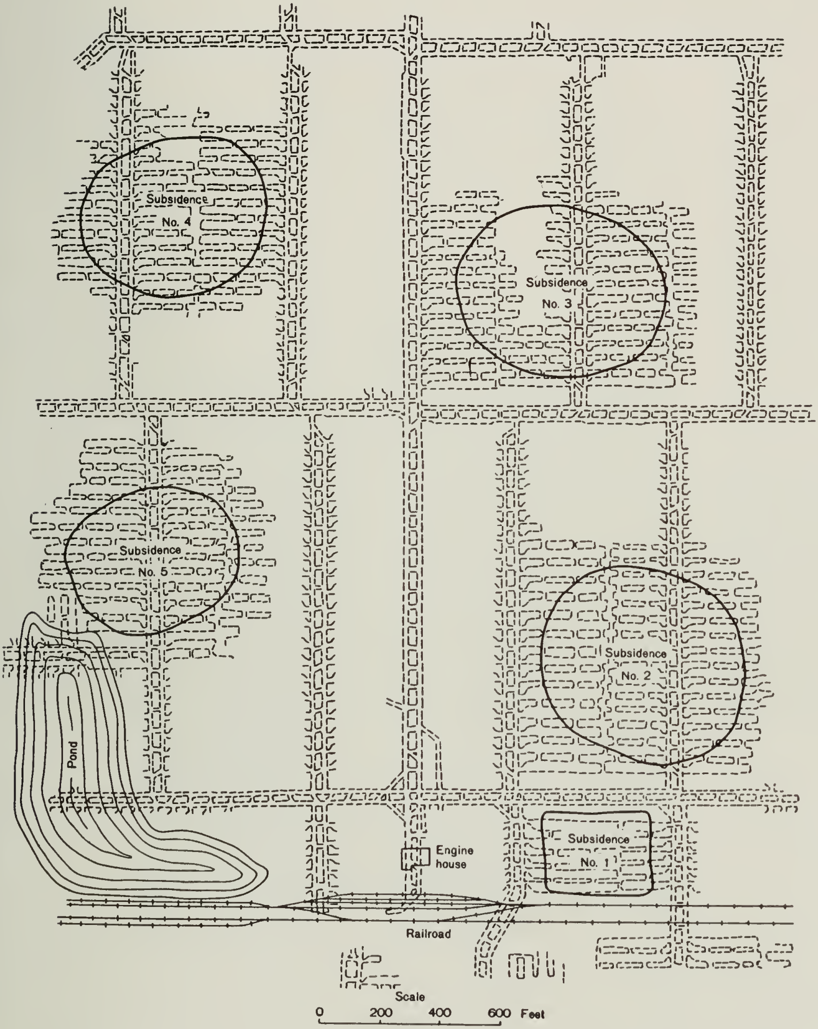

FIG. 25.—Plan of a mine in Perry County showing relation of sags to underground workings.

The subsidence occurred over an area of 44 rooms in a panel in which the entry pillars were 20 feet wide. The cut-throughs in the rooms were staggered 60 feet apart and were 20 feet wide. Where the room barrier on the west had been broken through, the squeeze worked over into the zone which had previously subsided. Where the barrier pillar was still intact, it was sufficient to check the movement, and directly above on the surface tension cracks appeared extending in the same general direction as the barrier pillar. There was a gentle sag to the east between the room barrier and the entry pillar. As this pillar was small and broken by cross-cuts, the squeeze rode over it,

FIG. 26.—Telephone poles tipped toward a sag over a Franklin County mine where an 8-foot coal is being removed at a depth of 450 feet.

and some subsidence resulted, although the deepest portion of the sag was transversely across the panel of rooms. The underground movement covered an area approximately 500 by 1,000 feet.

In April, 1915, at the same mine, squeezes occurred in two adjoining panels each of which consisted of 32 rooms. The rooms were turned with wide necks and were worked out quickly. No pillars were drawn. About 3 months after the rooms had been finished, a severe squeeze began. The easterly panel was badly crushed in 3 days, and the squeeze rode over the small barrier to the next panel on the west. Falls began in the west panel on the fifth day and continued for about one week. At the end of two weeks no evidence showed that any considerable surface movement had occurred. In July, 1915, the next panel east caved, and in a few days several sidewalks were cracked and tension cracks appeared in the dry earth.

In many districts room-and-pillar mining has caused extensive sags which have eventually become swamps. The trees, unsuited to the changed conditions, have been killed and the entire area has become

FIG. 27.—Swamp in a typical sag in Randolph County where a 6-foot coal is being mined at a depth of 150 feet. The rooms are on 50-foot centers; pillars 18 feet.

a waste. Somewhat typical illustrations of such swamps are shown in figures 27 to 31.

Frequently swamps of this nature are formed in the spring within fields and interfere with the plowing and planting. During the summer these ponds may dry up, and as a result there may be within fields large untilled and wasted areas.

In figure 31 is shown a Vermilion County cornfield containing an unworked area at least 200 feet square. Similar conditions have been noted in many of the coal districts (fig. 32). Not only may occasional ponds be created, but at times large sections may be lowered beneath the flood levels of river bottoms. There has been considerable litigation in northern Illinois where coal is being mined in the Illinois River bottom. It has been claimed by property holders that lands

Fig. 28.—Pond 4 feet deep and covering an area of about an acre, due to subsidence near Clifford, where a coal bed about 7 feet, 6 inches is being mined at a depth of 140 feet. Considerable quicksand occurs in the vicinity. The rooms are driven 20 to 22 feet wide on 40-foot centers, and no pillars are drawn.

Fig. 29.—Flooding of a large tract in Franklin County caused by mining of a 8-foot coal at a 460-foot depth. Rooms were carried 30 feet wide on 45-foot centers; no pillars were drawn.

were inundated on account of the increased amount of water flowing into Illinois River due to the discharge through the Chicago Drainage Canal. On the other hand the officers of the Chicago Sanitary Dis-

FIG. 30.—Pond caused by subsidence at Westville, Vermilion County, where 6 feet of coal was removed by room-and-pillar mining at a depth of 210 feet. Levels at surface show maximum depth of sag to be 4.7 feet. (Photo by R. Y. Williams.)

FIG. 31.—Open space south of Danville about 200 feet square in cornfield, indicating the area is not tilled because water stands over the sag in the spring.

FIG. 32.—Drowned-out area of corn near Nokomis where the 8-foot coal bed is worked at a depth of about 625 feet.

trict claimed that the lands were flooded because coal-mining operations lowered the lands beneath the former drainage levels.

Agriculture and Surface Subsidence

IMPORTANCE OF AGRICULTURE

Illinois is preeminently an agricultural and manufacturing state. To the manufacturing interests an ample and continuing fuel supply is of prime importance. In few states are both agriculture and manufacturing developed to so great an extent, and in practically no other state do the coal beds underlie so extensive and so fertile farm lands. In a large part of the Appalachian and the western coal fields the surface is almost valueless for agricultural purposes, but where the overlying surface is tilled it is of much less value than the farm lands of Illinois.

EXTENT AND VALUE OF FARM LANDS

In the accompanying tables are given data from the United States States Census for 1910 showing the percentage of the area in farm lands, the average value of the land per acre, and also the value of the coal produced in 1910.

The farm lands of Pennsylvania constituted 64.8 per cent of the area of the State, whereas only 68.2 per cent of the farm land was improved, or 44.2 per cent of the total area of the State. In the leading bituminous county of Pennsylvania (Table 4) 62.6 per cent of the land was in farms, and in Washington County, which, among the coal counties ranks high in the fertility of soil, the percentage of total area in farms was 91.3. In the three counties important as anthracite producers, the percentage of area in farms ranges from 43.5 to 47.2. The average value of land per acre in Pennsylvania was $33.92; in the five leading bituminous counties (excluding Allegheny[2]) the range was from $22.01 to $55.21; whereas in the anthracite counties the range was from $25.03 to $33.68.

In the leading coal-producing county in West Virginia only 37.8 per cent of the land was in farms, and 13.6 per cent of the farm land was improved or 5.14 per cent of the area of the county. The average value of the land per acre was $33.42. In one important coal-producing county 93.1 per cent of the land was in farms, yet the average value was only $43.81 per acre.

In Kentucky 86.3 per cent of the land was in farms, and 64.7 per cent of the farm land was improved or 55.84 per cent of the total

[2]The census reports the average value of land per acre in Allegheny County to have been $146.21. This high value is due to the fact that Pittsburgh and Allegheny are located in this county.

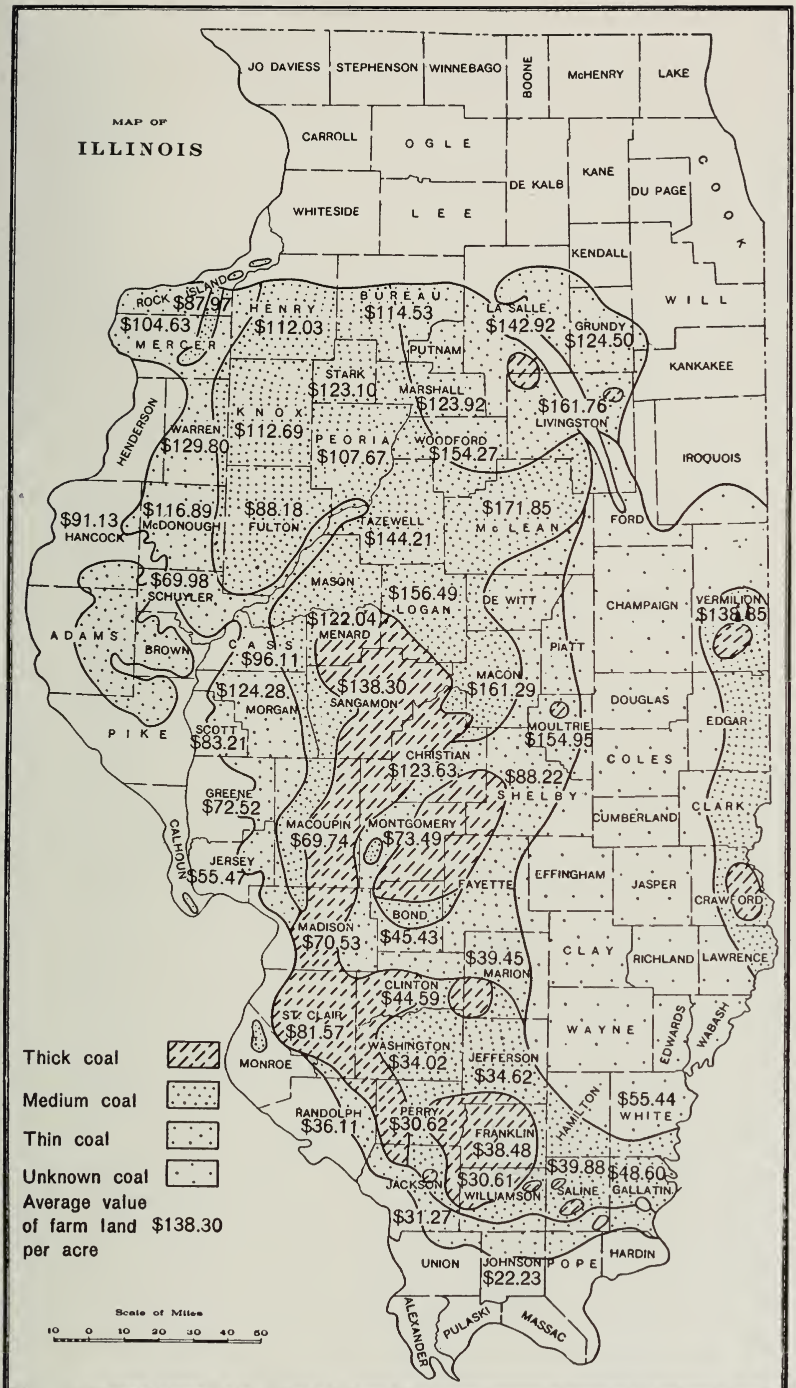

FIG. 33.—Map showing relation of different thicknesses of coal to the values of farm lands as given in the 1910 census.

area. The average value of the land was $21.83 per acre. In one of the leading coal-producing counties of Kentucky 81.2 per cent of the area is in farms, and 29.2 per cent improved, or 23.71 per cent of the total area. The land in this county has an average value of $11.72.

In Illinois 90.7 per cent of the area was in farms, and 86.2 per cent of the farm-land area was improved, or the improved land was 78.18 per cent of the area of the State. The average value of the land per acre was $95.02. In Sangamon County, an important coal producer, 87.33 per cent of the land was improved, which is 9 per cent better than the average for the State. The average price of land in Sangamon County was $138.30 per acre, a value of $43 more than the average for the State. The average price in Vermilion County, another important coal producer, was $138.85. The average price for La Salle County was $142.92. In the southern coal counties the farm lands are less valuable, but in Franklin and Williamson counties the percentage of land improved is greater than in the best counties of any of the states previously mentioned, whereas the average prices per acre, $38.43 and $30.61 respectively, compare favorably with the average prices of lands in the other states.

With the "Coal Measures" covering 66.9 per cent of the entire area of Illinois, and over 90 per cent of the area of the State in farms, the average value of which is at present greater than the average price of coal rights, the problem in Illinois of protecting the surface, particularly agricultural lands, is much different and much more important than the problem in most of the other coal-mining states. As previously noted, over 15,000 square miles are underlain by coal beds over 4 feet thick, and at least 10,000 square miles additional carry a bed 3 feet thick. Beds no thicker than 3 feet are being mined in Illinois and in other states; and it is only a matter of time until the problem of lowering the surface of one-half the State by an appreciable amount must be considered, if at least a fair extraction of the coal is desired. The average value of land per acre in the counties in the coal districts of Illinois is shown in Table 4 and on figure 33.

TABLE 4.—*Value of farm lands, April 15, 1910, (U. S. Census)*

States and counties	Approx. land area	Land in farms	Per cent of land in farms	Per cent of farm land improved	Average value of land per acre	Value of coal* production in 1910
	Acres	*Acres*				
Illinois	35,867,520	32,522,937	90.7	86.2	$95.02	$ 52,405,897
Bureau	563,840	524,455	93.0	87.9	114.53	1,488,070
Christian	448,000	422,520	94.3	96.4	123.63	1,322,162
Clinton	309,120	280,440	90.7	87.2	44.59	1,092,752
Franklin	284,800	222,578	78.1	86.8	38.48	2,312,342
Fulton	565,760	506,222	89.5	70.6	88.18	2 253,307
Gallatin	216,320	162,693	75.2	86.0	48.60	85,000
Greene	329,600	308,579	93.6	79.3	72.52	14,330
Grundy	277,120	249,984	90.2	91.6	124.50	968,563
Henry	527,360	504,927	95.7	90.6	112.03	225,018
Jackson	376,320	305,759	81.2	71.7	31.27	776,363
Jefferson	385,920	336,340	87.2	85.2	34.62	15,000
Knox	455,040	424,381	93.3	81.6	112.69	54,174
La Salle	733,440	662,755	90.4	91.3	142.92	2,032,002
Livingston	667,520	646,551	96.9	97.5	161.76	262,056
Logan	394,880	381,478	96.6	95.7	156.49	469,657
Macon	374,400	356,946	95.3	95.9	161.29	387,713
Macoupin	550,400	511,225	92.9	80.2	69.74	3,479,049
McDonough	376,320	353,776	94.0	85.7	116.89	61,194
McLean	762,240	733,161	96.2	96.0	171.85	29,470
Madison	471,680	408,487	86.6	86.8	70.53	4,222,078
Marion	364,160	335,624	92.2	85.5	39.45	801,117
Marshall	253,440	232,456	91.7	84.2	123.92	466,724
Menard	202,880	192,910	95.1	91.7	122.04	464,375
Mercer	345,600	326,311	94.4	83.2	104.63	343,115
Montgomery	440,960	426,398	96.7	89.4	73.49	1,907,006
Moultrie	216,320	207,249	95.8	94.2	154.95	3 800
Peoria	407,040	353,206	86.8	80.3	107.67	1,042,478
Perry	288,640	234,915	81.4	80.2	30.62	1,411,553
Randolph	375,680	323,237	86.0	76.8	36.11	1,065,969
Rock Island	271,360	237,936	87.7	77.7	87.97	109,433
St. Clair	424,320	364,523	85.9	84.9	81.57	5,763,249
Saline	255,360	213,831	83.7	85.9	39.88	2,713,514
Sangamon	560,640	520,999	92.9	94.0	138.30	5,014,237
Shelby	494,080	461,878	93.5	92.1	88.22	179,291
Stark	185,600	175,719	94.7	91.4	123.10	53,056
Tazewell	414,080	374,528	90.4	87.7	144.21	210,824
Vermilion	589,440	534,385	90.7	93.6	138.85	2,691,574
Warren	349,440	326,653	93.5	86.5	129.80	5,086,928
Washington	359,040	329,135	91.7	82.6	34.02	22,500
White	324,480	285,027	87.8	92.1	55.44	27,172
Will	540,160	498,651	92.3	89.2	104.08	126,362
Williamson	287,360	227,642	79.2	84.4	30.61	5,086,928
Woodford	337,920	316,064	93.5	87.4	154.27	121,131

*Mineral Resources of United States for 1910, U. S. Geol. Survey, 1911.

TABLE 4.—*Value of farm lands, April 15, 1910, (U. S. Census)*—Concluded

States and counties	Approx. land area	Land in farms	Per cent of land in farms	Per cent of farm land improved	Average value of land per acre	Value of coal* production in 1910
	Acres	*Acres*				
Kentucky	25,715,840	22,189,127	86.3	64.7	21.83	14,405,887
Henderson	278,400	231,677	83.2	86.7	36.08	239,332
Hopkins	349,440	298,263	85.4	60.7	20.28	2 202,299
Muhlenberg	302,080	245,210	81.2	29.2	11.72	2,503,371
Ohio	373,760	338,211	90.5	55.1	9.97	746,611
Pike	498,560	481,370	96.6	26.3	8.82	869,501
Pennsylvania	28,692,480	18,586,832	64.8	68.2	33.92	313,304,812
Bituminous—						
Allegheny	464,000	308,342	66.5	79.4	146.21	20,359,650
Cambria	458,886	228,004	49.7	57.2	32.59	17,566,903
Clearfield	730,880	271,094	37.1	59.5	22.01	8,048,056
Fayette	508,800	318,475	62.6	66.4	55.21	31,210,480
Washington	551,680	503,923	91.3	85.7	48.03	17,567,634
Westmoreland ...	664,960	493,491	74.2	74.9	42.03	22,389,051
Anthracite—						
Lackawanna	288,640	134,160	46.5	43.8	33.68	36,868,765
Luzerne	570,880	269,486	47.2	51.1	28.64	52,759,185
Schuylkill	497,280	216,348	43.5	65.8	25.03	28,998,199
Virginia	25,767,680	19,495,636	75.7	50.6	20.24	5,877,486
Tazewell	339,840	270,581	79.6	60.7	34.58	1,169,981
Wise	268,800	122,874	45.7	41.8	22.79	3,274,809
West Virginia	15,374,080	10,026,442	65.2	55.1	20.65	56,665,061
Fayette	426,880	110,142	25.8	48.8	24.72	10,135,369
Harrison	266,240	247,835	93.1	84.6	43.81	3,814,791
Kanawha	550,400	252,402	45.9	53.8	23.45	6,518,055
McDowell	341,120	128,784	37.8	13.6	33.42	12,767,998
Marion	201,600	173,529	86.1	76.0	39.91	4,165,737
Raleigh	382,080	139,134	36.4	46.9	27.15	3,309,678

*Mineral Resources of United States for 1910, U. S. Geol. Survey, 1911.

VALUE OF COAL LANDS

Although it is impossible to give an average value for coal lands in Illinois, yet it may not be out of place to indicate at what prices coal lands and coal rights are being sold. From these data some idea of the relation between the present value of the surface and of the coal can be obtained, and possibly a better idea of the prospective value of Illinois coal may be secured by a study of these data.

In a report[3] on the value of coal land made by the United States Geological Survey in 1910, the following royalty rates per ton of mine-

[3]Ashley, G. H., Valuation of public coal lands: U. S. Geol. Survey Bull. 424, p. 10, 1910.

TABLE 5.—*Value* of surface and of coal rights by counties in Illinois*

County	Value of coal per acre	Number of coal bed	Average surface value, census of 1910
Bond	$ 25	6	$ 45.43
Bureau	10–100	2	114.53
Christian	10– 50	6	123.63
Franklin	35–100	6	38.48
Fulton	15–100	5	88.18
Gallatin	20– 25	5	48.60
Grundy	10– 25	2	72.52
Henry	135	6	112.03
Jackson	25– 75	2, 6	31.27
La Salle	10–100	2, 5	142.92
Livingston	10– 50	6	161.76
Logan	20– 50	5	156.49
Macoupin	15– 50	6	69.74
Madison	10– 40	6	70.53
Marion	20	6	39.45
Marshall	15	2	123.92
McLean	15	5	171.85
Menard	25– 30	6	122.04
Montgomery	25– 50	6	73.49
Morgan	20– 30	6	124.28
Peoria	20– 50	5	107.67
Perry	25	6	30.62
Putnam	15	2	104.69
Randolph	25	6	36.11
St. Clair	10–100	6	81.57
Saline	50–150	5	39.88
Sangamon	20–100	5, 6	138.30
Scott	10– 40	2	83.21
Shelby	10– 25	6, 5	88.72
Vermilion	100–150	6, 7	138.85
Warren	15	1, 2	129.80
Will	15	2	104.08
Williamson	50–150	6	30.61
Woodford	15	2	154.27

*These prices are not offered as an authoritative basis for valuation but indicate in a general manner the prices at which coal has been sold or at which it is held in some of the important counties.

run coal were given for Illinois: northern Illinois, 5 cents; southern Illinois, 2 cents; La Salle district, 10 to 25 cents per ton of screened coal.

In 1914, the leasing rates were reported in various counties as follows: Franklin, 3 cents; Fulton, 3 to 4 cents; Henry, 12½ cents;

Jackson, 3 to 5 cents; La Salle,[4] 10 to 15 cents; Peoria, 8 cents; Perry, 3 cents; Rock Island, 20 cents; Vermilion, 3 cents; and Williamson, 3 cents.

Table 5 shows the range of prices for coal rights, depending upon the proximity to operating shafts and developed lands.

The United States Geological Survey[5] gives the following sale prices for 1910: Illinois, $10-150; Grundy district, $40-110; Rock Island district, $50-75; Springfield district, $10; and southern Illinois, $25-50.

In response to an inquiry regarding the assessed value of coal lands in Illinois in 1913, the various assessors furnished the data given in the accompanying table.

TABLE 6.—*Assessed valuation of coal rights and of agricultural lands by counties*

County	Assessed value of coal rights in 1913			Assessed value of farm lands not including improvements and coal	Remarks
	Highest	Lowest	Average		
Christian	$ 5.00	$ 5.00	$ 5.00	$77.18	Includes improvements, but not coal.
Fulton	35.00	35.00	35.00	60.00	
La Salle	7.00	1.53	4.89	20.51	
Livingston ..	10.00	10.00	10.00	27.50	Reduced for 1914.
Logan	....	....	....	90.00	Coal rights not assessed.
Madison	7.00	7.00	7.00	22.00	
Menard	7.00	7.00	7.00	20.00	
Mercer	18.00	11.00	14.50	11.00	Average of land for which coal right is assessed separately.
Perry	....	....	....	30 00	Improved; coal rights not assessed.
Putnam	....	....	3 50–5.00	....	
Randolph	11.00	8.00	8.69	23.46	Full value.
St. Clair	60.00	3.00	25.00	50.00	Not including E. St. Louis.
Saline	10.00	3.00	6.00	25.00	Including improvements.
Scott	....	....	....	....	Coal rights not assessed.
Washington .	5.00	3.30	3.80	8 09	

NATURE OF DAMAGE TO AGRICULTURAL LANDS

As previously noted the removal of the coal may cause (1) the caving of the surface with the formation of cracks and pit holes; (2)

[4]In the La Salle district most of the coal mined is owned by the mining companies, and very little is leased.

[5]Ashley, G. H., Valuation of public coal lands: U. S. Geol. Survey Bull. 424, p. 35, 1910.

the sagging of the surface, resulting in the derangement of natural and artificial drainage; (3) the fracturing of beds containing or preserving water supply; or (4) damage to surface improvements. With the proper care on the part of the mine operator some of these damages may be prevented or reduced. (See Chapter V.)

In the main it may be said that damage to farm property is only temporary, and the land and property can be restored. On the other hand when a portion of the coal is left in the ground as support for the surface, it is irretrievably lost, at least according to our commercial standards of the present time. In discussing mining wastes in Illinois, Mr. G. S. Rice[6] said:

"If it were possible to systematize mining (longwall) so that the land nearest the water courses was first undermined and then in succession the land farther away, the damage done to farming would be minimized. However, until the agricultural land of the United States becomes insufficient to fill the needs of the population, which would be reflected in a continual increase of price for farming land, the money loss from temporarily destroying the surface in places is relatively small as compared with the selling price of the coal mined under the same. Taking the average value of the surface at $125.00 per acre, if 80 per cent be rendered worthless, the immediate money-loss would be $100 per acre. A seam 6 feet thick would contain per acre 11,000 tons of coal in place, yielding at 90 per cent, 9,900 tons. The damage done by practically destroying the surface would be only 1 cent per ton. If the land prices should rise two or three times above the value stated, this loss would still not prohibit mining."

It may be suggested that under average conditions in Illinois at present 45 per cent of the coal is left in the ground in certain portions of the State largely to prevent surface subsidence. If an additional 35 per cent were recovered and damage to the surface should thereby result to the extent suggested by Mr. Rice, the increased output per acre, 3,850 tons, may be charged with the surface damage, assuming that ordinary mining costs remain the same (they would probably be reduced) with the increased tonnage. At a price of $125 per acre, the cost per ton for surface damage would be 2.6 cents. Many mining operators figure on this basis, and their experience has been that as a rule they are obliged to pay damages greatly in excess of the actual depreciation in value of the property.

The suggestion has been made frequently that the mining company should purchase the surface as well as the coal right, and that as soon as the coal has been mined completely under each tract or farm, the property should be restored as nearly as possible and sold. Under such conditions the surface would propably be as valuable when restored after the coal had been mined as when first purchased The income from the use of the surface for agricultural purposes would have

[6]Rice, G. S., Mining wastes and mining costs in Illinois: Ill. State Geol. Survey Bull. 14, p. 218, 1909.

been sufficient to pay the interest on the money invested in the land. If the company suffers any loss through the depreciation of the surface it would be small as compared with the damages that would be paid to the surface owner under conditions such as now exist in the coal-mining districts.[7]

RESTORING AGRICULTURAL LANDS

Where the removal of the coal causes local sags or depressions, water may accumulate to such an extent that artificial drainage must be provided. If the sags are of small area the problem may not be particularly difficult or expensive.

Figure 34 shows the position of 3 sinks with regard to the

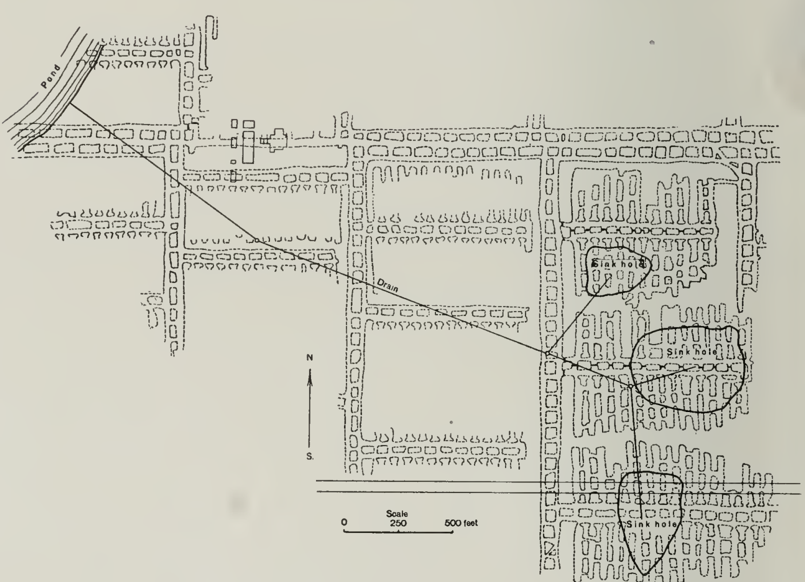

FIG. 34.—Map showing location of tile drains laid by a mining company to drain sags caused by mining a 7-foot coal at a depth of 330 feet.

workings of a room-and-pillar mine. At a depth of 330 feet a 7-foot coal was mined. Rooms were carried 30 feet wide with 30-foot pillars. The floor is fire clay, and it is thought the squeezes were due largely to the soft bottom. In order to remove the water in the ponds formed after the subsidence, the mining company laid 4,800 feet of tile at a cost of $647.57. The sags were from 2 to 3 feet deep. The coal was mined from 3 to 5 years before the subsidence occurred.

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[7]Most of the mining companies are not now in a position to invest the additional amount necessary to purchase the surface.

At a longwall mine in the northern part of the State it was found advisable to construct a sump and to install a pumping plant in order to drain a pond which was caused by surface subsidence. As a general rule, it is found more economical to lay drain tile at possibly greater first cost.

Where breaks or pit holes result from mining operations, if the surface is valuable, it will usually pay to fill the holes partly with refuse and then to surface with a layer of soil sufficiently deep to support vegetation. The Agricultural Department of the University of Illinois recommends that the soil cover should be not less than 4 feet in depth. If the soil in its natural state is less than 4 feet thick over the entire area, it would seem equitable to make the soil layer of the filled area of equal thickness with that of the undisturbed area.

FIG. 35.—Pit hole filled with rubbish at the Electric mine near Danville.

In figure 35 is shown what frequently occurs in the mining district—the dumping of all kinds of rubbish into the cavities without regard to the ultimate dressing of the surface with soil. Figure 36 shows the practice in an area adjacent to Streator where the holes are filled partly with mine rock. Figure 37 shows a field near Streator in which the holes have been filled and then dressed with soil. The darker area in the foreground shows the fresh filling. The hole filled was 20 feet in diameter and averaged about 6 feet in depth.

Occasionally a subsided area extends across a road. In many places water collects and forms a pond that extends over the road.

In order to make the road passable it may be filled to grade with the material most easily accessible.

In order to prevent surface water from entering pit holes and thence flowing into the mine below, it frequently becomes necessary to construct dikes around the largest holes and those holes located

FIG. 36.—Pit hole and cracks caused by mining at a shallow depth near Streator. Mine rock near the hole has been hauled for filling; the surface will then be dressed with soil.

FIG. 37.—Pit holes near Streator caused by room-and-pillar mining filled with mine rock and surfaced with soil. The dark lines border the area of filling.

in the deepest part of the sags or in the course of the drainage of storm water. A dike 3 feet high built around a pit hole 60 feet in diameter and 28 feet deep has been constructed near Dewmaine.

It may be stated in general that, except where the "Coal Measures" are overlaid with thick beds of quicksand or other material that will flow easily, there will be little irreparable damage to the surface on account of coal-mining operations, particularly when the coal is removed completely. If a considerable portion of the coal is left permanently in pillars, the surface will probably be thrown into hummocks and sags, with occasional breaks and ponds. A complete removal of the coal will leave the surface in a much better condition for farming purposes. If the rock cover is thin and the overburden has a tendency to flow into the mine, special precautions must be taken or the surface will be considerably broken, due to the flow of sand into the workings.

At present attempts at filling the mine workings by flushing seem to be impracticable for the greater portion of the Illinois coal fields owing to the scarcity of material suitable for filling. If surface material is taken, a considerable area will be rendered unfit for agricultural purposes due to the removal of the soil. In portions of the State, however, it is possible that in the future market conditions may warrant higher mining costs, and under such conditions hydraulic stowing of crushed material from surface quarries may be feasible.

Transportation and Surface Subsidence

RAILROADS

The practice of separating the mining right from the title to the surface has frequently resulted in mining beneath roads, streets, and railroads without any consideration of the protection of the surface. In many instances the deed for the mining rights specifies that the coal may be removed completely and without a liability for damage to the surface. In other instances in which damage to the surface has resulted, an effort has been made to remove as large a portion of the coal as possible without injury to the surface. Certain railroads have permitted mine entries to be driven across the right-of-way and have forbidden the opening of rooms within a specified distance of the center of the track. In several cases mining has been carried on according to the regulation of the railroad, but the removal of coal outside the reserved area has resulted in "draw" or "pull" which has threatened the railway tracks. Railways have been constructed across tracts which have previously been undermined by the room-and-pillar system and on which no subsidence has occurred. In time the pillars have weakened, and the added burden and the vibration due to the passing trains have resulted in the sinking of the tracks. In the opinion of a number of experienced railroad engineers the problem of subsidence as affecting railroads is much different from that affecting other types of property, due principally to the intermittent and moving loads.

Few instances have been recorded in Illinois of the loss of life or injury to patrons or employes of railroads resulting directly from subsidence due to mining beneath the right-of-way.

Figure 38 shows the partially regraded railway track over a mine in which 9 feet of coal has been worked at a depth of 425 feet. In the distance the work train can be seen as filling material is being

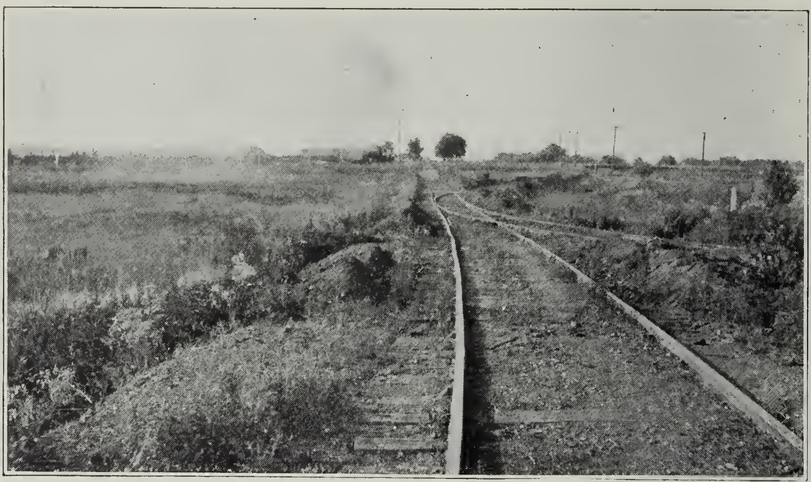

FIG. 38.—Railroad track in Franklin County lowered by surface subsidence resulting from room-and-pillar mining of a 9-foot coal at a depth of 425 feet. The maximum subsidence was 4 feet. The track has been partially repaired.

unloaded for the regrading of a switch. Figure 39 shows the nature and extent of the workings beneath the surface tracks which have subsided. The rooms were carried 30 feet wide by 300 feet long; pillars were 20 feet wide. The squeeze covered an area 1,200 feet square, and the depression at the surface was in places 4 feet. The underclay is quite soft in parts of the mine.

One of the large railroad companies reports that in the La Salle district it has been necessary to raise and surface the main line track every year, the total subsidence being estimated at about 3 feet. It is reported by two railroad companies that subsidence resulting from longwall mining in the vicinity of Decatur has necessitated regrading and filling amounting to 3 to 4 feet.

Room-and-pillar mining in southern Illinois has caused considerable damage to railroad tracks. Near Duquoin a track to a mine subsided 3 feet. A branch line of a railroad in Williamson County was damaged by a sink hole 6 feet in diameter and 20 feet deep. This occurred over the abandoned workings of a mine 90 feet deep. Important tracks have subsided amounts varying from a few inches to a few feet at numerous places. Important bridges have been threat-

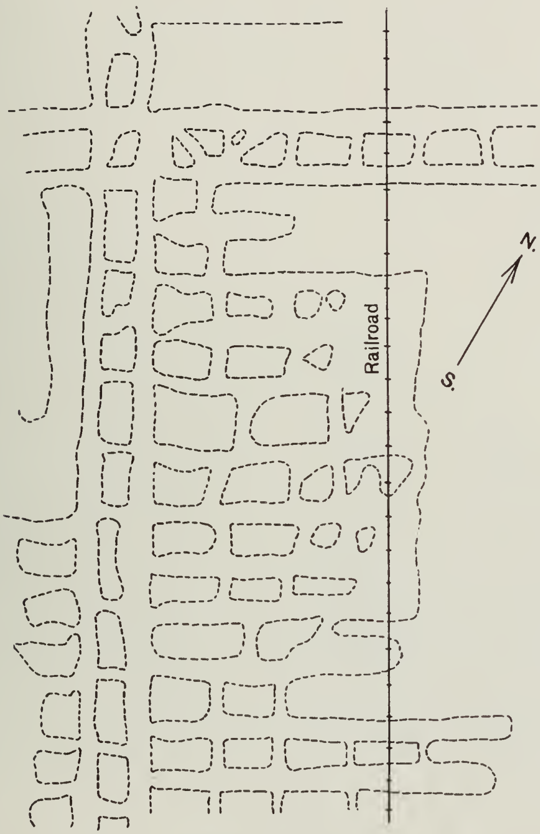

Fig. 39.—Plan showing relation of railroad in figure 38 to mine workings.

ened; one pier of a bridge is reported to have subsided 18 inches but without much tilting (fig. 40).

It is now the practice of the railroad companies whose lines extend through mining districts to secure annually from their division engineers complete reports showing the extent of mining beneath the right-of-way.

WAGON ROADS

Generally the title to the coal beneath wagon roads is not reserved by the district maintaining the roads. Frequently where there is a likelihood that the roads may be damaged by mining operations an agreement exists between the mining company and the local officers to the effect that any damage to any road will be repaired by and at the expense of the mining company.

In the Longwall District of northern Illinois a general subsidence following the advance of the longwall face in many places results in the inundation of the roads during part of the year. At a number

Fig. 40.—Repaired railroad trestle in Franklin County. One end subsided 18 inches more than the other, the total having been reported as about 4 feet. Timbers were placed at A, B, C, and D in order to reduce the sag of the track over the trestle.

of places the mining companies responsible for the subsidence have constructed adequate ditches paralleling the sunken road in order to remove the water. It is not uncommon for the mining companies, as important users of the roads, to haul mine refuse and ashes to fill the road to the desired grade.

STREAMS AND CANALS

Mining has been carried on beneath several navigable streams and canals, but in no instance has the water been let into the mine, nor has subsidence caused any appreciable damage to the water course

—at least not to the extent of interfering with its usefulness for the passage of watercraft.

Buildings and Improvements Affected by Subsidence

BUILDINGS

The subsidence of the surface over a large area may be so uniform and so gradual as to cause no serious damage. In parts of the longwall field mining has been reported to have had no appreciable effect upon the frame buildings at the surface. The effect is less if the mining face advances rapidly and across the shorter axis of the building. As previously noted, the building is in a tension zone as the mining face approaches and passes under the building, and the section of the building under which the coal has been removed first tends to tilt toward the mine and to tear itself free from the remainder of the building. If the building is constructed of masonry,

Fig. 41.—House near Coal City lowered 9 inches at one corner, caused by mining a 3-foot coal at a depth of 125 feet.

serious cracks may form and afterward close when the mining face has advanced completely beyond the building.

When the advance of longwall mining has been stopped under or adjacent to a building, the surface is likely to be tilted enough to throw the building out of plumb. Figure 41 shows a house in the Coal City district which was thrown out of plumb by the stopping of the longwall face near the house. The coal beneath had not been mined. The seam of coal is 3 feet thick and lies at a depth of 125 feet. One corner of the house was almost one foot lower than the other corners.

The removal of part of the coal by room-and-pillar mining is more likely to damage buildings seriously than is the complete removal of the coal by the longwall system. This difference results from the probable formation of pits and from the unequal subsidence that may tear to pieces a building that happens to be located over a pillar. If it is located in the middle of a small sag, the compression or squeezing may be so great as to destroy the building.

Figure 42 shows the part of a brick house still standing above a pillar in a mine near Danville. Approximately 6 feet of coal was taken out at a depth of 200 feet. The position of the house with regard to the mine workings is shown in figure 43.

FIG. 42.—Brick house near Danville abandoned on account of danger by room-and-pillar mining of a 6-foot coal at a depth of about 200 feet.

Figure 44 shows a portion of a row of houses in Springfield These brick houses were damaged by subsidence resulting from room-and-pillar mining. The coal is 5 feet 9 inches thick and lies at a depth of approximately 200 feet. A pillar 10 feet wide was left along the street and this apparently was responsible for the cracking of the houses. If all the coal had been removed the houses probably would have settled uniformly. The houses have been repaired at the expense of the mining company.

In figure 45 is shown a small frame house in the suburbs of Streator. A pit hole 10 by 20 feet and 5 feet deep has been formed along one side of the house.

In southern Illinois has recently occurred a movement affecting a large area in one of the coal-mining towns. Eight feet of coal was being mined by the room-and-pillar method at a depth of approximately 450 feet. Rooms were carried 30 feet wide with 15-foot pillars. Figure 46 gives a general view showing the flooded streets resulting from the subsidence. The maximum depth of the sag was about 3 feet. The foundations of houses were cracked, and in a

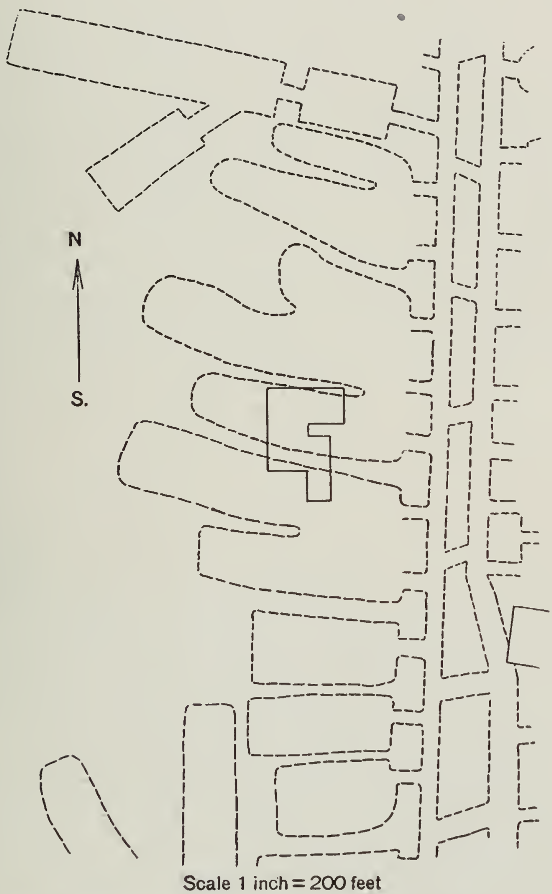

FIG. 43.—Plan showing relation of house in figure 42 to the pillar in the mine.

number of houses the plaster fell. Another depression at the same mine resulted in lowering one end of the company barn over 4 feet. The barn has been repaired, but one end is still approximately 15 inches lower than the other. The tilting of the barn is shown in figure 47.

FIG. 44.—Houses in northwest Springfield for which claims were paid by a mining company for damages caused by mining a coal 5 feet 9 inches thick at a depth of about 200 feet.

FIG. 45.—Small house near Streator beside which a pit hole 10 by 20 feet and 5 feet deep has formed.

STREETS, PIPE LINES, AND SEWERS

Mining within the limits of cities and towns and the construction of towns upon lands which have previously been undermined have been attended with more or less danger owing to the subsidence of the streets. Where coal at shallow depth has been mined by the room-and-

Fig. 46.—Flooded streets, broken sidewalks and foundations, and damages to plastering resulting from subsidence in Franklin County. Figure 48 shows the broken sidewalk at A. (Photo by H. I. Smith, U. S. Bureau of Mines.)

Fig. 47.—Barn of mining company lowered 4 feet at one end. It has been partially restored.

pillar system, a sudden collapse of the overlying beds into the worked-out rooms may result. Passing teams have at several times been reported to have dropped with the surface into a pit hole. No fatal accidents are known. Where the coal is at greater depth, or where the coal has been mined by the longwall system, the movement will probably not be attended by the formation of holes into which buildings or creatures may fall.

The gradual sinking of the surface may do serious injury to pavements, sidewalks, car tracks, pipe lines, and sewers. Numerous instances of such damage have been reported but as repairs are usually made immediately there has been little opportunity to secure photographs illustrating this type of damage.

Figure 48 shows a broken sidewalk caused by subsidence. Mining was being carried on by the room-and-pillar method at a depth of 450 feet on an 8-foot seam of coal.

Fig. 48.—Broken sidewalk caused by subsidence in Franklin County; the location is shown in figure 46. (Photo by H. I. Smith, U. S. Bureau of Mines.)

In order to secure reliable information regarding the extent of mining operations within the towns of the State, and the nature and amount of damage which has been attributed to mining, a general letter was sent in August, 1914, to the mayor of each of 80 more or less typical incorporated towns and cities in the coal districts. Replies[8] were received from 56.

[8]The towns reporting were Auburn, Belleville, Bloomington, Braidwood, Breese, Carbondale, Carterville, Christopher, Colchester, Coulterville, Duquoin, Edinburg, Fairbury, Farmington, Galesburg, Geneseo, Harrisburg, Hillsboro, Jacksonville, Kewanee, Lewistown, Lincoln, Litchfield, Lovington, Macomb, Marion, Marissa, Mascoutah, Mattoon, Minonk, Morris, Mount Olive, Moweaqua, Murphysboro, Nashville, Nokomis, Norris City, Odin, O'Fallon, Pana, Peoria, Peru, Pinckneyville, Pontiac, Riverton, Salem, Seneca, Shelbyville, Sorento, Springfield, Spring Valley, Staunton, Streator, Virden, West Frankfort, and Witt.

The questions and answers were as follows:

1. Has coal ever been mined within the city limits? Yes, in 48 towns of 56 replying.
2. Has coal ever been mined under the streets and alleys? Yes, in 39 towns of 56 replying.
3. Has any damage resulted to the streets and alleys on account of the mining of the coal? Yes, in 5 towns of 56 replying; no, in 49.
4. Does the city now own or control the right to mine coal under any or all of the streets and alleys? Yes, in 17 of 56 replying; no, in 35.

The replies to question No. 3 received from the five cities and towns reporting damage to streets and alleys were as follows:

1. Yes.
2. Not recently, but in former years some subsidences caused some trouble. These have been fixed except one that gives some trouble, but nothing serious.
3. A little.
4. Some cave-ins.
5. Yes. Sink on North Main Street and property adjoining it; also in east and west part of city.

The mayor of one town in which a 7-foot seam of coal lies at a depth of less than 450 feet reports that "the city has deeded the right to mine coal under all its streets to the ——— Coal Company, and they have been mined as far as Main Street." The coal company reports that 50 per cent of the coal is left unmined, the rooms being from 30 to 35 feet wide on 55-foot centers. The mining company has not been released from surface damage. There has recently occurred in this town a movement which damaged a railroad right-of-way.

Another mayor wrote as follows: "The right to mine coal under streets and alleys was voted to ——— Coal Company several years ago." At this place the coal is 7 feet thick and is over 600 feet below the surface.

A city in the Longwall District of northern Illinois receives a yearly rental for the privilege of mining coal under the streets. A city ordinance granted this privilege conditional upon the payment of the rental.

WATER SUPPLY

At a number of places in the State it has been reported that wells have ceased to furnish the usual supply of water owing to the cracks and fissures resulting from subsidence. In some instances water-bearing rocks have been shattered, and in others gravel beds and catchment basins have been tilted or disturbed so that they no longer serve as reservoirs for water. However, in a number of instances after the subsidence movement has stopped, the surficial beds have become compact and have again furnished water in quantities nearly, if not quite, as great as previously.

MUNICIPAL WATERWORKS

The protection of city waterworks is a matter which merits serious attention. At several points, notably at two cities of over 50,000 population, mine workings are advancing toward the waterworks. In these two large cities the undermining of the wells, reservoirs, and plants will cause serious damage.

Reservations of Coal

The topic of reservations may logically be considered under the discussion of protection of the surface and directly in connection with pillars. It has been more or less customary for the owners of farm lands when selling the coal right to reserve a tract of the coal under the dwelling, the well and cistern, the barn, and any important farm buildings adjacent to the dwelling. The advisability of leaving a small tract of coal for the protection of the surface is seriously questioned. If the coal is not thick and can be removed rapidly and completely it may be much more economical to have the coal taken out and to make such minor repairs as may result from subsidence. The presence of faults and beds of quicksand would complicate matters.

Moreover under some conditions the angle of draw may be so great that for the depth at which the coal occurs the size of reservation necessary for adequate protection would be entirely out of proportion to the value of the objects on the surface for which protection is desired.

There are no statutes in Illinois forbidding mining under any particular type of structures, public utilities, or other buildings, although there are such statutes in some states. When it can be shown that irremediable damage would result to property used for public purposes, or when mining might seriously threaten life through damage to property used for a public purpose, an injunction may be secured restraining mining in the area where subsidence is feared.

CHAPTER IV—SUBSIDENCE DATA BY DISTRICTS

Introductory Statement

As the reports upon the mining practice and upon the geology have assembled the data by districts, it has been thought advisable to review the data on subsidence by districts so that they may be correlated with the geological and mining data.

The location of the various districts is shown in figure 49. Table 7 gives the districts of the State by counties and Table 8 gives the counties arranged alphabetically.

Table 7.—*Districts into which the State has been divided for the purpose of investigation*

Investigations district	Coal seam	Method of mining	Counties
I	2	Longwall	Bureau, Grundy, La Salle, Marshall, Putnam, Will, Woodford.
II	2	Room-and-pillar	Jackson.
III	1 and 2	Room-and-pillar	Brown, Calhoun, Cass, Fulton, Greene, Hancock, Henry, Jersey, Knox, McDonough, Mercer, Morgan, Rock Island, Schuyler, Scott, Warren.
IV	5	Room-and-pillar	Cass, DeWitt, Fulton, Knox, Logan, Macon, Mason, McLean, Menard, Peoria, Sangamon, Schuyler, Tazewell, Woodford.
V	5	Room-and-pillar	Gallatin, Saline.
VI	6 (East of Duquoin anticline)	Room-and-pillar	Franklin, Jackson, Perry, Williamson.
VII	6 (West of Duquoin anticline)	Room-and-pillar	Bond, Christian, Clinton, Macoupin, Madison, Marion, Montgomery, Moultrie, Perry, Randolph, Sangamon, Shelby, St. Clair, Washington.
VIII	6 and 7 (Danville)	Room-and-pillar	Edgar, Vermilion.

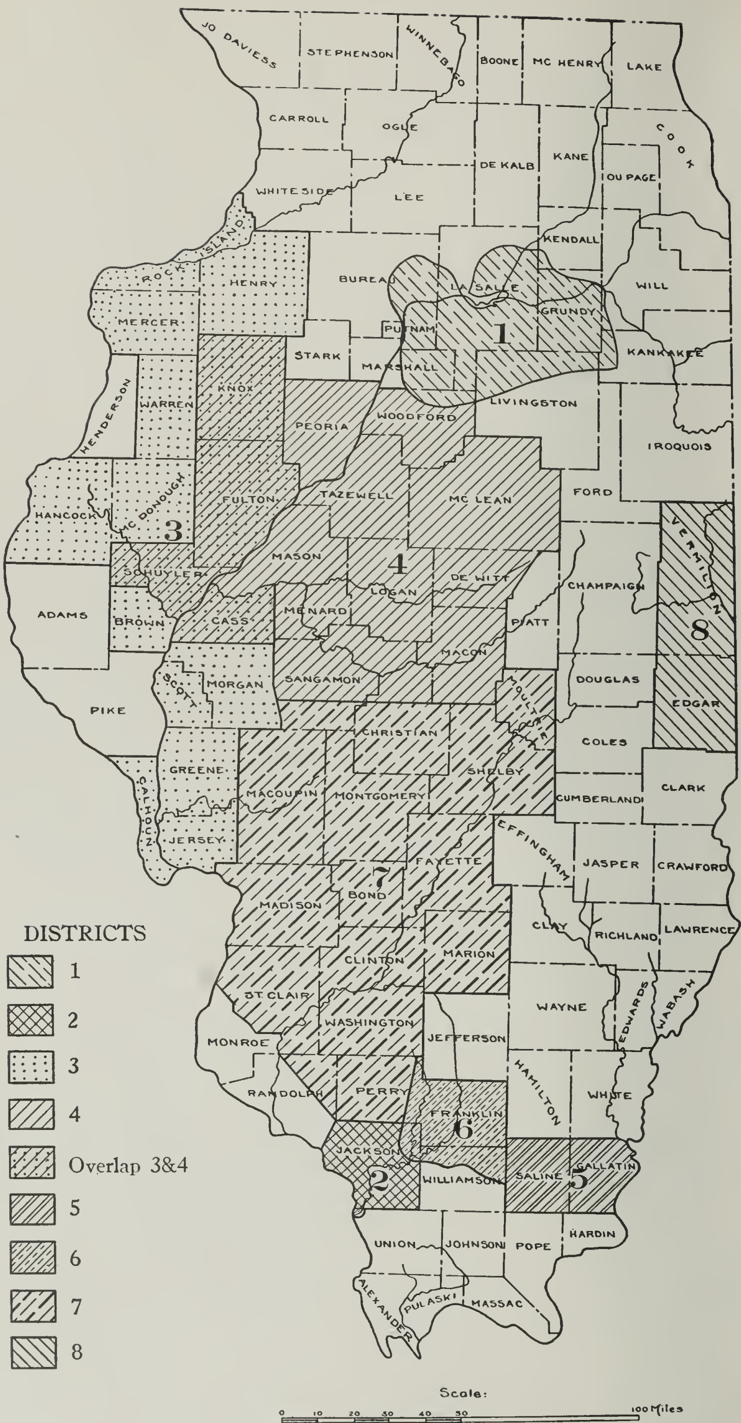

Fig. 49.—Map showing division of State into districts.

TABLE 8.—*Alphabetical arrangement of coal-producing counties*

County	Coal seam	District	County	Coal seam	District
Bond	6	VII	Marshall	2	I
Brown	1, 2	III	McDonough	1, 2	III
Bureau	2	I	McLean	5	IV
Calhoun	1, 2	III	Menard	5	IV
Cass	1, 2, 5	III, IV	Mercer	1, 2	III
Christian	6	VII	Montgomery	6	VII
Clinton	6	VII	Moultrie	6	VII
Edgar	6, 7	VIII	Peoria	5	IV
Franklin	6	VII	Perry	6	VI, VII
Fulton	1, 2, 5	III, IV	Putnam	2	I
Gallatin	5	V	Randolph	6	VII
Greene	1, 2	III	Rock Island..	1, 2	III
Grundy	2	I	St. Clair	6	VII
Hancock	1, 2	III	Saline	5	V
Henry	1, 2	III	Sangamon ...	5, 6	IV, VII
Jackson	2, 6	II, VI	Schuyler	1, 2, 5	III, IV
Jersey	1, 2	III	Scott	1, 2	III
Knox	5	IV	Shelby	6	VII
La Salle.....	2	I	Tazewell	5	IV
Logan	5	IV	Vermilion ...	6, 7	VIII
Macon	5	IV	Warren	1, 2	III
Mason	5	IV	Washington .	6	VII
Macoupin ...	6	VII	Will	2	I
Madison	6	VII	Williamson ..	6	VI
Marion	6	VII	Woodford ...	2, 5	I, IV

These districts do not contain quite all the mines operating in Illinois because there are a few which do not fall into the arrangement such as the Assumption mine, 1004 feet deep, operating in coal No. 1 at Assumption in Christian County and a few small room-and-pillar mines in coal No. 2 in the longwall field. From the mines included in the eight districts of the Coal Mining Investigations, however, there is produced 98.3 per cent of the tonnage of the State, and 97.6 per cent of all the employes in coal mines in Illinois work in these districts.

DISTRICT I

Practically all the longwall mines of the State are included in District I. In Table 9 is given a list of longwall mines arranged according to depth and showing the average thickness of coal worked. It will be noted that the majority of the mines are being worked through shafts more than 300 feet deep. Of the 36 shafts only 2 are more than 600 feet deep, and these are outside of the longwall district proper.

Reference has previously been made to the character of roof and floor in District I. Attention may be called again to the extension over a part of the district of a heavy bed of limestone 25 to 30 feet thick and lying 375 to 400 feet above coal No. 2 and 175 feet above coal No. 7. Data are not available to show to what extent this bed influences the surface movement resulting from longwall mining, but it is reported that where the limestone bed is known to occur, the sinking of the surface does not follow so soon after the coal has been removed as in those areas where the limestone is known to be missing

Table 9.—*Longwall mines in Illinois*

Operator and mine	Post office address of mine	Geological number of seam	Depth of coal below surface	Thickness of seam	
			Feet	*Ft.*	*in.*
1. Murphy, Linskey & Kasher	Braidwood	2	61	3	3
2. Wilm. C. Mg. & Mfg. Co., No. 6	Torino	2	100	3	6
3. Big Four Wilm. C. Co.	Coal City	2	100	3	4
4. Wilm.-Star Mg. Co., No. 7	Coal City	2	126	3	..
5. G. & J. Coal Co., No. 1	Seneca	2	130	3	..
6. Fulton Co. C. Mg. Co., No. 1	Sparland	2	165	2	8
7. Chic. Wilm. & Fr. Coal Co., No. 1	S. Wilmington	2	186	3	2
8. Chic. Wilm. & Fr. Coal Co., No. 3	S. Wilmington	2	187	3	2
9. Ill. Zinc Co., No. 3	Peru	2	336	3	6
10. Spring Valley Coal Co., No. 1	Spring Valley	2	339	3	4
11. Ill. Zinc Co., No. 1	Deer Park	2	364	3	3
12. La Salle Co. Carbon Coal Co.	La Salle	2	390	3	4
13. Spring Valley C. Co., No. 4	Seatonville	2	393	3	4
14. Spring Valley C. Co., No. 5	Dalzell	2	421	3	4
15. La Salle Co. Carbon C. Co., No. 1	La Salle	2	440	3	4
16. Spring Valley C. Co., No. 3	Spring Valley	2	457	3	4
17. Oglesby C. Co.	Oglesby	2	464	3	6
18. Ill. Third Vein C. Co.	Ladd	2	468	3	6
19. Roanoke C. Co.	Roanoke	2	480	2	8
20. St. Paul C. Co., No. 2	Cherry	2	485	3	6
21. St. Paul C. Co., No. 1	Granville	2	486	3	..
22. B. F. Berry C. Co., No. 1	Granville	2	505	3	..
23. Rutland C. Co., No. 1	Rutland	2	511	2	10
24. Toluca C. Co., No. 1	Toluca	2	512	2	10
25. McLean Co. C. Co.	Bloomington	2	525	3	6
26. LaSalle Co. Carbon C. Co., No. 5	La Salle	2	545	3	6
27. Minonk C. Co., No. 2	Minonk	2	550	2	8
28. Mfrs. & Consumers C. Co.	Decatur	5	560	4	6
29. Decatur C. Co., No. 2	Decatur	5	612	4	6
30. Assumption C. Mg. Co.	Assumption	1 & 2	1004	4	..

and where there is the same total thickness of overlying sedimentary rocks.

Data from 10 shafts ranging from 50 to 550 feet in depth showed the average subsidence as follows in percentage of thickness of the coal mined:

Depths up to 200 feet, subsidence averaged 55 per cent.
Depths from 200 to 400 feet, subsidence averaged 50 per cent.
Depths from 400 to 550 feet, subsidence averaged 39 per cent.

Sufficient data are not available to warrant the use of the foregoing figures as the basis of estimates of general subsidence in the Longwall District.

For all depths the amount of subsidence depends largely upon the quality and quantity of material stowed in the gob. It should be observed that as the depth increases, the weight of the overlying rock increases in proportion, and the material in the gob in deeper mines would probably be compressed more than the gob in shallower mines. With the same quality and quantity of material in the gob, all other underground conditions being the same, there may be as great a vertical movement of the surface when coal is mined at 600 feet as when the same thickness is mined at 200 feet. Some companies do not report that subsidence has occurred at their mines, and some question whether it actually occurs on their property. This probably is an honest statement resulting from the lack of established monuments and the failure to take elevations from time to time to show actual changes in the surface. In the greater part of the district, however, it is generally acknowledged that some subsidence results, but it is claimed that the surface movement is inappreciable in most places and does not cause damage to property on the surface.

As previously noted one of the most common forms of damage is by the flooding of lands by creation of sags or the sinking of areas below the previous drainage channels or flood plains (see figure 24). Some damage to buildings has been done but only little has been serious (see figure 41). Brick buildings have suffered more than frame buildings. No brick building has been irremediably damaged. Foundations have been cracked, but where all the coal has been removed and the longwall face has advanced well beyond the structure, the cracks have partly closed. Several long buildings have been badly cracked when the longwall face has not been advanced rapidly as the coal beneath the building was being removed. In three towns the occasional trouble with water and gas mains is attributed to subsidence resulting from mining.

In this district, one of the oldest mining districts in the State, there have been relatively few lawsuits on account of surface damage resulting from subsidence. Most of the claims for damages have arisen on account of the flooding of lands, and these have usually been adjusted out of court.

District II

This district comprises Jackson County. The commercial coals lie at shallow depths, the deepest shaft being 165 feet. The coal varies in thickness from 3 feet 6 inches to 9 feet, and one small mine is operated on a bed 12 feet thick. All the mining is done on the room-and-pillar plan. The percentage of coal recovered, as reported for four representative mines, ranges from 44 to 55, the average being 48.5. Due to a thin cover over a large territory and considerable sand in the surface beds, a great deal of damage to the surface has occurred in certain areas. It may be said that in general the territory damaged has not been particularly valuable for farming purposes. Where the coal lies at greater depths, gentle sags from 1 to 3 feet deep may occur.

Little litigation in this district has resulted from subsidence. It is generally recognized that the mining of the coal at shallow depths must cause surface damage, and the coal is relatively much more valuable than the surface in Jackson County.

District III

This district includes room-and-pillar mines on coals No. 1 and No. 2 in the northwestern part of the State. The mines of this district were not visited in connection with this investigation, but some data upon subsidence have been collected in connection with other investigations. The commercial coal beds lie at shallow depths, a large proportion of the mines being opened by slopes and drifts. In general the room-and-pillar system of mining is employed.

The deepest mine examined in the district during the cooperative investigation is 210 feet deep, but the most of the hoisting shafts are not over 100 feet deep. In several of the mines where underground conditions are favorable, the longwall system can not be used because the lowering of the surface and the breaking of the thin rock cover is likely to permit the inflow of water and sand.

In parts of the district conditions permit of systematic pillar drawing and, where a large percentage of the pillar coal is removed, surface subsidence occurs. Owing to the thick surficial beds,[1] considerable draw is likely to result from extensive falls. In several places the movement of surficial material has extended laterally a considerable distance, and in one case reported farm buildings, not undermined, have suffered damage.

[1]The log of one of the shafts records 125 feet of surficial material.

Where pillars are drawn and extensive falls occur, cracks 2 to 12 inches wide have appeared on the surface within a period of two weeks to three months. The depression following the removal of 44 inches of coal has varied from 12 to 20 inches, the average being 40 per cent of the thickness of the coal. Where the cover is thin and the surficial beds are deep, pit holes will form instead of sags. Owing to the hilly nature of the country little damage has resulted by the formation of sags.

Comparatively little litigation has been due to subsidence in this district, most of the claims for damages having been adjusted by the interested parties.

District IV

This district includes the room-and-pillar mines on coal No. 5 in the north-central part of the State. The surface in District IV is in part flat, and in part hilly. The important coal bed outcrops in the northern and western counties and reaches a depth of 600 feet in parts of Macon County. Coal is mined extensively at a number of points; in all there are about 250 mines, shipping and local, in the district. The average thickness of the coal is given as 4 feet 8 inches.[2] In most of the mines either the room-and-pillar system or a modified panel system is used. However, in several mines the longwall system is employed.

In but few of the room-and-pillar mines are the pillars drawn, and the average extraction for the room-and-pillar mines of the district is 54 per cent. In one-half the mines included in the cooperative investigation, squeezes have occurred. "Where there have been so many squeezes under comparatively shallow cover surface, subsidence is to be expected. Surface cracks and subsidence seem to be related to the absence of limestone cap rock. Where sandstone is the cap rock subsidence is more marked."[3]

In the special study of subsidence in this district 15 mines were visited, and in all some subsidence was apparent or reported by the mining company.[4] In but few places has serious damage resulted. Owing to the incomplete removal of the coal over any large areas, in most of the room-and-pillar mines of the district the pillar coal prevents subsidence in the form of extensive and regular sags. Where

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[2]Andros, S. O., Coal mining practice in District IV: Ill. Coal Mining Investigations Bull. 12, p. 15, 1915.

[3]Idem, p. 29.

[4]It should be stated that it was the general plan to visit mines at which it was reported that subsidence had occurred. The 15 mines visited were more or less typical mines, but it should not be inferred that subsidence has occurred at all the mines of the district.

subsidence occurs over the parts of mines in which all the pillar coal has not been recovered, the surface may be broken by pit holes or caves or may be thrown into irregular hummocks and sags. Where the coal is worked near the outcrop, extensive areas are badly broken by caves (see figures 15 and 17). Where the surficial material is wet, it may run into the rooms when the roof breaks. The wet material may slip and run until the sides of the cave are on an angle of 25 to 30 degrees. Where possible some of these holes have been filled and now show on the surface as sags because of the settling of the filled material.

Data on 10 fairly typical mines are given in the accompanying table. Except for the two shallow mines, the extraction averages about 55 per cent.

Table 10.—*Data on subsidence in District IV*

Depth of shaft	Thickness of coal	Evidences of subsidence
Feet	*Inches*	
35	58	Surface cracks and breaks, pit holes.
75	60	Surface cracks and breaks, pit holes.
160	54	Sags 18 inches deep; some cracks.
175	72	Sags 24 to 36 inches.
185	54	Surface rolling; some cracks and sags.
200	72	Sags 18 to 36 inches.
200	69	Sags 12 to 18 inches.
240	69	Sags 12 to 18 inches.
245	72	Sags 12 to 18 inches.
250	69	Sags 12 inches.

Comparatively little litigation has been the result of subsidence in this district except where the mines are located adjacent to large towns. A number of the mining companies operating in the suburbs of towns which have grown toward the mining location have been obliged to pay claims for damages to residences (see figure 44). One of the large companies reports that claims for damages have been so excessive that it has been found expedient to leave over 40 per cent of the coal to prevent subsidence. The president of this company claims that coal in this vicinity is worth $200 per acre to a developed mine and $100 per acre to a new mine. On this basis the coal left in the ground is worth from $40 to $80 per acre mined.

In the river bottoms the principal damage following mining has been the formation of sags that have been filled with flood water in the spring. A number of these cover extensive areas made unfit for cultivation except in years of light rainfall.

When the coal right is not owned by the mining company, and the coal is mined on a royalty basis, the mining company does not usually assume liability for damage to the surface. Moreover, it is to the financial interest of the owner of the coal to have the extraction as complete as possible. Considerable coal is mined on this basis in this district, and therefore relatively little friction exists between the agricultural and the mining interests.

District V

The principal mines of Saline and Gallatin counties are opened upon coal No. 5. There are 21 shipping and 12 local mines in the district. In Saline County the average thickness of the bed is 5 feet 4 inches, and the depth from 25 to 400 feet.[5]

The problem of surface support, as well as that of the complete removal of the coal, is made more difficult by the occurrence of horses and faults. Mining is conducted by the room-and-pillar system, and the percentage of coal gained in the mines examined in the cooperative investigation ranged from 58.6 to 81.5, the average of seven mines being 67.1.

In the mines along the outcrop, considerable damage results to the surface by breaks and pit holes (see figure 13). When the coal lies at greater depths, cracks and sags may occur over the squeezes and extensive falls.

In figure 14 are shown two areas, A and B, which subsided as a result of squeezes adjacent to dikes. A 5-foot coal bed is mined at an approximate depth of 300 feet. The depressions are about 2 feet deep and are flooded part of the year.[6] In another mine in the same district, due to the mining of a 6-foot coal at a depth of 265 feet, subsidence occurred adjacent to a fault. The break on the surface appeared 6 hours after the mine examiner had passed through the workings below. The surface subsided 2 feet 6 inches.

Mr. R. Y. Williams reports that in another mine in the same district a squeeze occurred December 23 to 26, 1914. The area affected underground covered about three acres. The squeeze occurred on the northeast side of a dike. Figure 15 shows the mine workings in relation to the dike. A number of pillars had been drawn where the coal was about 8 feet thick and where the cover was approximately 150 feet. The logs of holes No. 2 and No. 3 are given below.

[5]Andros, S. O., Coal mining practice in District V: Ill. Coal Mining Investigations Bull. 6, p. 9, 1914.

[6]It is estimated that tile could be laid for ¼ mile for $400.

The rooms were 28 feet wide, and the pillars 12 feet. In order to stop the squeeze, cogs 6 to 8 feet square were built of 4- to 6-inch timber and filled with gob. Some of the cogs were 10 to 12 feet long by 6 to 8 feet wide. On the surface a few cracks appeared, but as the country is rolling it was impossible to observe the movement of the surface without the taking of measurements.

Log of drill hole No. 2

(Elevation at surface 341.24)

Description of strata	Thickness		Depth	
	Ft.	*in.*	*Ft.*	*in.*
Surface	18	..	18	..
Sand shale	20	..	38	..
Fire clay	1	..	39	..
Sand rock	10	..	49	..
Blue shale	29	1	78	1
Coal	2	11	81	..
Blue shale	2	..	83	..
White sand rock	3	..	86	..
Blue shale	14	..	100	..
Black slate	4	9	104	9
Coal	..	1	104	10
White sand rock	3	3	108	1
Blue shale	42	..	150	1
Coal	6	4	156	5
Sand rock	..	10	157	3

Log of drill hole No. 3

(Elevation at surface 285.09)

Description of strata	Thickness		Depth	
	Ft.	*in.*	*Ft.*	*in.*
Surface	14	..	14	..
Sand shale	6	..	20	..
Sand rock	5	..	25	..
Blue shale	5	..	30	..
Black slate	4	..	34	..
Blue shale	15	..	49	..
Iron bowlder	3	..	52	..
Coal	3	..	55	..
Gray shale	52	..	107	..
Coal	9	2	116	2

TABLE 11.—*Data on subsidence at typical mines in District V*

Depth of shaft	Thickness of coal	Evidences of subsidence
Feet	*Inches*	
150	72	Sag 24 inches deep.
225	72	Sag 30 inches deep (near a fault).
300	60	Sag 24 inches deep (near a fault).
400	56	Sag 18 inches deep.

Little litigation in this district has been due to surface subsidence. Owing to the hilly nature of the surface, the sags cause practically no damage to farm lands.

District VI

This district includes the mines opened on coal No. 6 east of the Duquoin anticline. There are 78 shipping mines in this district varying in depth from shallow mines along the outcrop to shafts a little over 700 feet deep. The average thickness of the coal is 9 feet 5 inches, the range being from 7½ to 14 feet.[7] In the year ended June 30, 1914,
folio (No. 185), 1912.
the mines of the district produced about 23.5 per cent of the tonnage of the entire State. In 1914 the extraction reported by the operators was 56 per cent of the coal in the bed.[8]

Most of the coal is free from horses, rolls, and faults. The nature of the roof and floor, as well as of the overlying strata, has been discussed in Chapter II.

Subsidence has occurred at many mines, both at those along the outcrop and at some of the deepest mines of the district. "With present dimensions when rooms have been driven 200 to 300 feet there is a large area of unsupported cap rock. If an attempt is made to draw pillars under such conditions a squeeze is usually started which often rides over room and entry pillars and sometimes affects large acreage. In one mine a squeeze covered 85 acres; in another 80."[8]

Data on subsidence were secured at 30 shipping mines. It has been impossible to formulate any definite statement in regard to the average amount of subsidence that has occurred or that may be expected for different depths and when specific percentages of coal are extracted. The statement is made generally throughout the district that if 40 per cent of the coal is left in room pillars there will be no surface subsidence. This statement should undoubtedly be qualified,

[7]Shaw, E. W. and Savage, T. E., U. S. Geol. Survey Geol. Atlas, Murphysboro-Herrin

[8]Andros, S. O., Coal mining practice in District VI: Ill. Coal Mining Investigations Bull. 8, p. 15, 1914.

and the maximum width of room specified for various depths as well as the percentage of coal to be left in pillars.

At a few places levels have been run on the surface both before and after subsidence. When the mining companies have reported subsidence and have given the depth of a depression on the surface, the depth given has usually been an estimate or a measurement of the depth of the deepest part of the sag below the general level of the surrounding territory.

The most reliable of the data collected in the district are condensed and presented in Table 12.

Table 12.—*Data on subsidence at typical mines in District VI*

Depth of shaft	Thickness of coal	Evidences of subsidence
Feet	*Inches*	
100	100	Breaks and pit holes.
115	96	Sags 60 inches deep and pits.
118	72	Sags 60 inches deep.
119	90	Pit holes.
120	108	Sags 48 to 60 inches deep and pits.
140	90	Sags 40 inches deep and pits.
140	108	Sags 60 inches deep and pits.
147	108	Sags 48 inches deep and pits.
150	90	Sags 48 inches deep and pits.
190	90	Sags 24 inches deep.
215	84	Sags 36 inches deep.
220	84	Sags 36 inches deep.
325	108	Sags 36 inches deep.
350	96	Sags 48 inches deep.
409	96	Sags 30 inches deep.
417	108	Sags 48 inches deep.
443	96	Sags 30 inches deep.
460	96	Sags 48 inches deep.
517	96	Sags 36 inches deep.

Little effort has been made to restore the surface where pit holes have been formed (see figures 12 and 19). This is due probably to the much smaller valuation of this land for agricultural purposes than the land in the northern part of the State, where it is not uncommon to fill the holes and to restore the general slope of the surface. As the country is much more hilly less damage results from sags and from the formation of ponds and swamps than in the prairie lands of District I.

Considering the amount of subsidence, there has been comparatively little litigation. Claims for damage to the surface are generally adjusted out of court. It must be expected that in this district of thick coal, where coal mining is probably the leading industry, more or less injury to the surface must be endured if the coal resources are to be properly utilized. Moreover, below the coal bed now being worked are other beds which undoubtedly will attract attention after coal No. 6 has been worked out, and this deeper mining may also be expected to cause surface movement in part of the district.

District VII

This district includes all mines operating in coal No. 6 west of the Duquoin anticline, and north as far as an east-west line about 6 miles south of Springfield. The 150 shipping and 46 local mines of this district produce nearly 40 per cent of the entire tonnage of the State. The thickness of the coal varies from 2½ to 14 feet, the average being 7 feet. The coal outcrops on the western side of the district and is deepest in Christian County where one shaft has opened it at a depth of 730 feet.

The coal is mined by the room-and-pillar and panel systems. The average per cent of recovery is 55; that is 45 per cent of the coal in the bed is left in the mine and probably will not be recovered in the future. Because of the large area of this district, the failure to bring to the surface a proper percentage of the coal in the bed is a matter for serious consideration. A contributing cause of this waste of natural resources is the fear of bringing about surface subsidence and attendant damage suits. It would probably be economy for the

Table 13.—*Data on subsidence at typical mines, District VII*

Depth of shaft	Thickness of coal	Evidences of subsidence
Feet	*Inches*	
70	72	Sags 60 inches deep and pit holes.
85	72	Pit holes.
160	84	Sags 40 to 50 inches deep.
190	90	Sags 48 inches deep.
300	75	Sags 24 inches deep.
325	100	Sags 12 to 60 inches deep.
328	100	Sags 42 inches deep.
330	84	Sags 30 inches deep.
385	84	Sags 20 inches deep.
400	93	Sags 24 inches deep.
408	78	Sags 30 inches deep.
430	90	Sags 14 inches deep.
435	96	Sags 18 inches deep.
450	96	Sags 14 inches deep.
466	96	Sags 12 to 18 inches deep.
470	96	Sags 18 inches deep.
585	102	Sags 24 inches deep.

operating companies to purchase the surface overlying the coal to be removed. Pillars could then be robbed and 30 per cent more of the coal bed could be recovered.[9]

As in a number of the other districts few data are available to show the actual difference in elevation of the surface before and after the coal has been removed. In most of the observations recorded in Table 13 the subsidence has been estimated or measured roughly by comparing the elevation of the low point of a sag with the general slope of the ground. In several instances the depth of filling required to bring railroad tracks to grade has been taken as an indication of the amount of subsidence.

In several of the smaller mining towns considerable damage to residences has resulted from surface subsidence, and some litigation has resulted, but most claims have been adjusted out of court. The mining company has made many of the repairs necessary to restore damaged buildings. One mining company has laid draintile to remove water standing in a sag caused by the mining of coal, and thus a valuable field has been made available for agriculture.

District VIII

As previously noted both coals No. 6 and No. 7 are mined in the Danville district. The beds lie at varying depths, the deepest shaft in the district being 240 feet. The irregularities in the coal bed, roof, and floor have been discussed in Chapter II. As it has not been advisable to drive the rooms a uniform width on account of the irregularities, pillars have been gouged in a number of mines. The percentage of extraction in six cooperative mines ranges from 55 to 82 and averages 71.5.

Adjacent to the outcrop where the coal beds have been mined by the room-and-pillar system large areas of the surface have been damaged by the formation of pit holes (see figures 16 and 35). In the deeper mines the squeezes that have frequently resulted from gouging pillars have often been attended with surface subsidence (see figures 30 and 31). The land back from the streams lies flat and is very fertile, and the formation of sags has caused considerable litigation when deed to the coal has not released the mining company from liability for surface damage. Sags have been measured at several points, one of the largest measured having a maximum depth of 4.7 feet. The coal bed mined in this vicinity was 210 feet deep and averaged 6 feet in thickness.

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[9]Andros, S. O., Coal mining practice in District VII: Ill. Coal Mining Investigations Bull. 4, p. 16, 1914.

Some damage has resulted to farm buildings and dwellings, largely because the coal was not removed completely from beneath the buildings. A building standing over a small pillar may be seriously damaged by the draw, and if the pillar left is not directly beneath the building, the building will be cracked seriously or broken by the tilting over the shoulder of the pillar (see figure 41).

CHAPTER V—PROTECTION OF SURFACE

General Considerations

Though, as has been noted, it may be unwarranted to assume that coal may be removed over large areas without disturbing the surface, it is well known that over small areas such as roadways, rooms, and even small panels of rooms, the coal may be removed, and the roof will arch or, if it falls, break up to such an extent that the broken material may fill the entire volume of the opening. Under such conditions severe subsidence can not result.[1]

Where coal beds are to be mined, the surface above may be protected from subsidence in several ways. In general, the most common and the most feasible are (1) by the use of pillars or artificial supports and (2) by filling methods.[2]

Pillars

In considering the service which a pillar may render, and in determining the size of the pillar for protecting specific mine openings or objects on the surface, it will be necessary to consider some of the following factors, in some cases all of them:

1. Unit strength of the material forming the pillar.
2. Height of the mine opening.
3. Dip of the mineral deposit.
4. Angle of "draw" or "drag" or "pull" over the pillars as observed in the district or under similar conditions.
5. Angle of break of the overlying rock.
6. Strength of the overlying rocks.
7. Nature and amount of filling in the mined-out area adjacent.
8. Depth at which mining may be carried on without affecting the surface.
9. Bearing power of the bottom or floor.
10. Weight of overlying materials that must be supported.

Crushing Strength of Coal

Strength tests have been made upon Illinois coal, but the data secured have not been sufficient to warrant the formulation of rules based upon crushing strength alone. Moreover, the advisability of placing much reliance upon data secured from such tests is questioned

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[1]This presumes that subsequently the weight of overlying measures does not compress the broken material to the same volume it occupied when solid.

[2]Frequently the total damage to the surface may be minimized by rapid and complete removal of the coal.

by many mining engineers on account of the difficulty of securing sample blocks of coal which are really representative of the entire thickness of the coal seam. The blocks usually tested represent the strongest layer of coal, the weaker bands frequently being so soft that a representative sample can not be secured. Where the weight comes on pillars of such banded coal, the softer bands are crushed, and the harder bands must give way until a more or less uniform bed of crushed coal furnishes a support.

The results of the tests upon Illinois coal are as follows:

TABLE 14.—*Compression tests* of Illinois coals*

Lab. No.	Location	Equivalent section		Height	Maximum load	
		Top	Bottom			
		Inches	*Inches*	*Inches*	*Lbs.*	*Lbs. per sq. in.*
12,401	Penwell Coal Co., Pana....	11¾x12	11¾x12	12½	316,000	2,090
12,402	Empire Coal Co...........	15⅕x17⅗	15 x15⅓	11.3	540,000	2,170
12,403	W. W. Williams, Litchfield.	13¼x13¼	14 x14	14½	186,000	1,000
12,404	Herdien Coal Co., Galva...	11½x17¼	16 x13	12	208,000	1,020
12,405	T. H. Watson, Litchfield...	13¾x12	13¾x12	15	224,000	1,360
12,406	C., W. & V. Coal Co., Streator	11¾x 9¼	11 x11¼	13	140,000	1,280

*Talbot, A. N., Compression tests of Illinois coals: Ill. State Geological Survey Bull. 4, p. 199, 1907.

ANGLE OF BREAK AND ANGLE OF DRAW

Considerable discussion has been carried on in Illinois in regard to the angle of break and the angle of draw. European engineers who have studied subsidence for a number of years have observed that there is a first break and then a main or after-break. The so-called "first break" corresponds more or less to the break observed in the immediate roof as the longwall face advances.

Mr. S. O. Andros in discussing mining practice and conditions in the longwall field of Illinois states that subsequent to the first break at the shaft pillar and face, if the gob area has been properly filled so that the roof weight rides on the face of the coal, other roof breaks occur every 2 inches to 6 feet parallel to the coal face extending upward away from the face and toward the gob as the face advances. The distance between breaks depends principally upon the character of the roof and the packing of the gob. At the face of solid coal the cracks in the roof are difficult to see; and they do not become easily visible (fig. 50) until the face has advanced 4 to 5 feet. The distance to which these mining breaks extend into the roof depends upon the roof material, but they rarely extend more than 15 feet above the coal. The angle made by these breaks varies from 50 to 90 degrees from the horizontal, depending upon the roof material and the rate of settling. In summer when the face progresses slowly the cracks are more nearly vertical.[3]

In a number of places it has been possible to observe the effect of subsidence upon the strata 10 to 20 feet above longwall workings. As reported by Mr. Andros, very few cracks have been in evidence in the overlying shales and the strata have apparently settled gradually

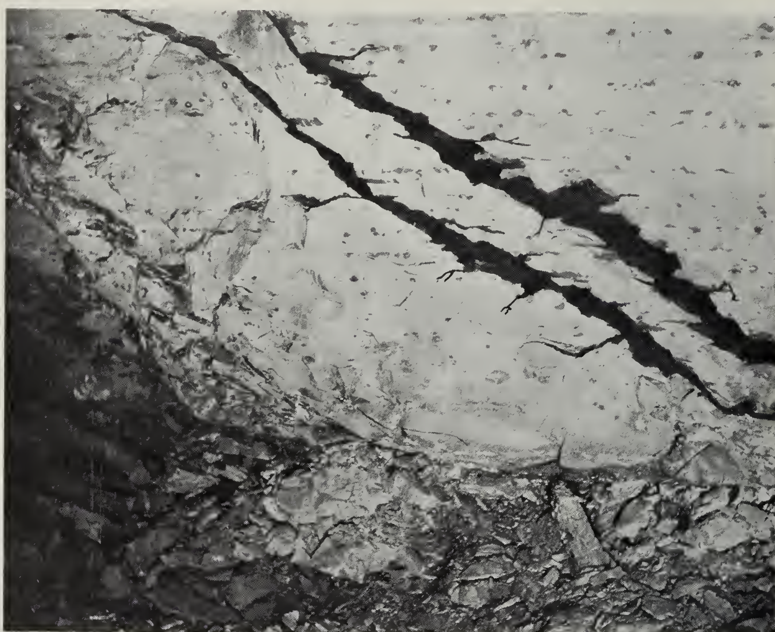

Fig. 50.—Cracks in the immediate roof of a longwall mine in the La Salle area. (Photo by S. O. Andros.)

and with but little fracturing, and such cracks as have resulted have evidently closed after the face has advanced.

Though the observations in Illinois supported the general statement that the breaks extend back over the gob and are usually not evident at a height of more than 20 feet above the coal bed, practically no available data support or oppose the theory and observations of European engineers—namely, that the angle of break in the immediate

[3]Preliminary report on organization and method: Ill. Coal Mining Investigations Bull. 1, p. 20, 1913.

roof is practically unimportant and that the important angle is the angle of draw (this of course refers to stratified rocks).

In discussing these angles the German engineer, Wachsmann, illustrated his observations by figure 5. The beds directly over the worked-out portion of the coal are broken by subsidence depending largely upon the amount and the nature of the packing. This zone of breaking is limited by the plane through BE. However the measures beyond BE are disturbed by the sinking of the beds immediately over the mine workings and the draw may extend to and is limited by the plane through CE. It is then the angle CED which is important rather than the angle of the local breaks in the immediate roof.

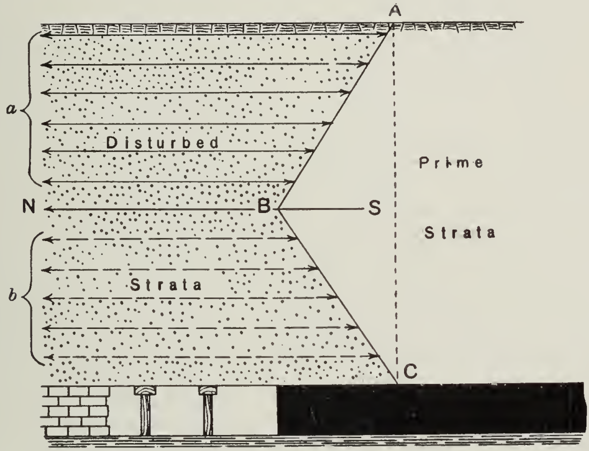

FIG. 51.—Stress diagram of an ideal homogeneous cantilever (after Halbaum).

Similarly British engineers have noted the angle of the local breaks in the immediate roof, but have given attention to the angle of draw as the more important and controlling factor in determining the size of shaft pillars and in indicating the probable limits of the general subsidence over extensive mine workings.

Probably this phase of subsidence has been discussed in more detail in a paper by Mr. H. W. G. Halbaum than by any other British engineer. Owing to the importance of a correct understanding of this phenomenon, as it applies to longwall mining in Illinois, the theory[4] of Mr. Halbaum will be presented in some detail.

"It may be conceived that the measures overlying the coal bed act as a cantilever where the coal is undermined. The cantilever rests upon

[4]Halbaum, H. W. G., The great planes of strain in the absolute roof of mines: Trans. Inst. Min. Engrs. vol. 30, p. 175, 1905-1906.

the solid unworked coal, the load consisting primarily of the weights of the measures themselves. The cantilever will be like other cantilevers in certain particulars. It possesses a neutral surface. Above this surface all the stresses in the beam of strata are of the tensile order. Below it all are of the compressive order. The uppermost tensile stress and the lowermost compressive stress are the maxima of their respective orders; and both orders of stress regularly diminish

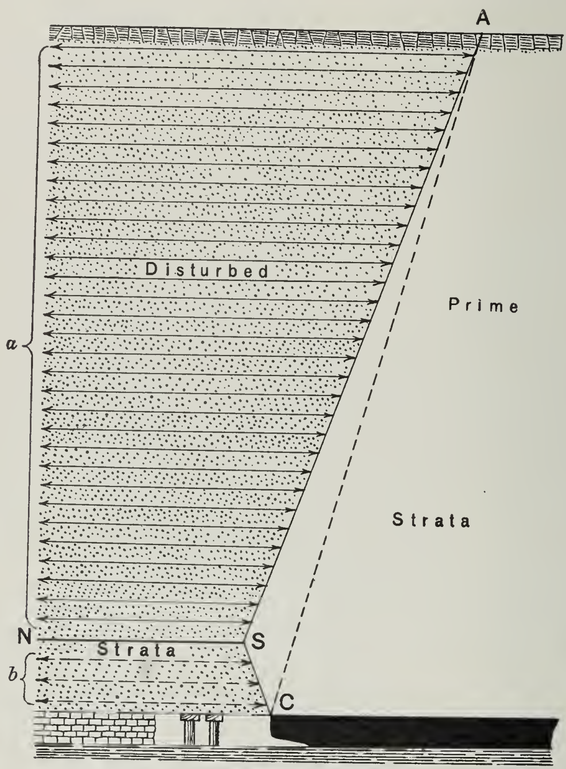

FIG. 52.—Stress diagram of a low-down neutral surface (after Halbaum).

as the planes on which they act approach nearer to the neutral surface, at which plane both kinds of stress are reduced to zero. Figure 51 shows the stress diagram of an ideal homogeneous cantilever, whereas figure 52 shows the stress diagram of a cantilever with a low-down neutral surface. In figure 51 the neutral surface is at NS, at half the depth of the beam. The stresses in the upper section, *a,* are tensional, and the stresses in the lower section, *b,* are compressive. ABC is the absolute line, and AC is the mean line of elementary strain; in this case, vertical. In figure 51 the neutral surface lies in the plane

NS. AS is the tensile component; SC the compressive component; and the broken line, CA, represents the mean elementary line of strain projecting over and toward the solid."

The idea that the main angle extends toward and over the solid coal is generally accepted by British engineers. According to this, subsidence will begin before the coal directly below (in the case of horizontal beds) has been mined. The size of this main angle is variable and depends upon the nature and dip of the strata and on the amount and character of the filling.

In Illinois a number of subsidences have been reported to have occurred in advance of the longwall face. Where pillars have been left to protect definite areas or buildings, it has been found that there is some subsidence over the edge of the pillar, but it is generally believed that this movement will occur only after the working face has been stopped for some time. Few data are available in Illinois either to prove or disprove the proposition that the wave of subsidence extends ahead of the longwall face as it advances. At one of the shallow mines in the longwall district a borehole was put down in advance of the coal, and when the longwall face reached the borehole an examination of the surface was made. It was found that subsidence had extended to the collar of the borehole and did not lag behind the longwall face.

Safe Depth

THEORY AS PREVIOUSLY ADVANCED

It has been argued by various engineers and mine managers that there is a depth below which it is feasible to remove all the coal without disturbing the surface and without introducing filling or making any special provision for filling. This theory is founded upon the assumption that after the coal has been mined the overlying beds break and fall and fill up the cavity produced by the removal of the coal. There is little evidence available in Illinois on which to base this theory, and a number of American engineers who have studied the problem agree that the "safe depth" theory is not logical.

INCREASE IN VOLUME OF ROCK BY BREAKING

In order that the effect of caving and crushing of overlying beds may be understood, it is important that the volume occupied by broken material be compared with the volume occupied by a unit of the same material when unbroken "in the solid." Extensive tests have been made by engineers to determine to what extent the volume of rock may be increased by crushing to various sizes. The French engineer

Fayol made elaborate tests, the results of which are shown in condensed form in the accompanying table.

TABLE 15.—*Volumes of different materials after crushing as compared with volume "in the solid"*

Nature of rock	Relative volumes					
	Unbroken	Crushed to powder	Grains 2 to 3 millimeters (.078. to .118 inch)	Grains 10 to 15 millimeters (.393 to .59 inch)	Grain 15 to 20 millimeters (.59 to .787 inch)	Mixtures of grain and fine dust
Clay	100	196	209	226	225	216
Shale	100	213	210	221	224	229
Sandstone ...	100	219	214	211	310	214
Coal	100	207	224	199	223	202

COMPRESSIBILITY OF BROKEN ROCK

Experiments have been made upon crushed material to determine to what extent it may be compressed. In general it is known to what extent rock in place, when crushed to a specified size, may occupy an increased volume when the crushed material is subjected to pressure. Fayol's results of compression tests upon crushed material are given in Table 16.

TABLE 16.—*Compressibility of different materials after having been crushed*

Nature of rock	Space occupied before being broken	Rocks having been previously crushed or broken occupy space indicated, under pressure*			
		I Pressure 1,422 lb. per sq. in.	II Pressure 2,844 lb. per sq. in.	III Pressure 7,110 lb. per sq. in.	IV Pressure 14,220 lb. per sq. in.
Clay	100	100	90	75	70
Shale	100	128	116	110	97
Sandstone	100	136	125	120	105
Coal	100	130	125	118	109

The following conclusion was drawn by Fayol: "The material which ordinarily fills the graves of mines always occupies a larger space than it did ordinarily. After an expansion of about 60 per cent, it appears to undergo in workings of from 300 to 900 feet in depth, a compression of about 30 per cent, which leaves a volume of about 12 per cent larger than the volume of the unbroken rock."[5]

*Pressure I corresponds to a depth of strata of 1,638 feet; II, 3,276 feet; III, 8,190 feet; and IV, 16,380 feet.

[5]Colliery Engineer, vol. 33, p. 548, 1913.

The United States Bureau of Mines[6] had made tests upon crushed material from the Pennsylvania anthracite districts (Table 17) to determine its compressibility (1) when confined in steel cylinders, (2) when built into cogs, and (3) when piled in heaps.

TABLE 17.—*Compressibility tests upon crushed material made by the United States Bureau of Mines*

Lbs. per sq. ft.	Corresponding depth, 140 lbs. per cu. ft. *Feet*	Compression (Reduction in height) *Per cent*
A. Broken mine rock and breaker refuse compressed in a steel cylinder 16⅞ inches in diameter and 25¼ inches high:		
20,000	143	11.4
30,000	215	15.5
90,000	645	24.0
120,000	860	26.2
B. Mine rock passing 1½-inch ring, lying loosely in a conical pile and free to flow:		
23,824	170	60.0
40,256	290	62.3
92,445	660	65.0
165,000	1,180	67.0
C. Rock cog, built of mine rock and shoveled material. Pyramidal form; base 5 by 5 feet; top, 3 by 3 feet; height, 1 foot 11 inches.		
22,000	167	22.0
30,000	215	27.0
90,000	645	36.0
120,000	860	37.2

From these data it may be stated that for the conditions of longwall mining where the gob is well filled and the walls well built, the compression of the gob will be only 33⅓ per cent more for a mine 645 feet deep than for a mine 215 feet deep. Data are not available to show how much the broken shale, commonly forming the gob in the longwall district, will be compacted under pressure. The weight of 100 feet of overburden is sufficient to make it deform and flow.

Where the mine roof falls into a free space it may be more or less shattered, and as overlying beds fall successively, the worked-out volume may be filled eventually. The material which can not fall sinks upon the fallen material which may have been already compressed to such an extent that it may be able to check further subsidence.

In longwall mining the argument has been that, as the beds overlying the gob subside, they compress the gob to a fraction of the thick-

[6] Unpublished data.

ness of the coal, and that as they sink they increase in volume sufficiently to prevent the movement extending to any great height above the coal horizon. As previously noted, observations in the Longwall District of northern Illinois tend to prove that as the roof along the roadways sinks, it breaks, and that cracks are formed extending parallel to the working face. These may be from 2 inches to 6 feet apart and usually extend up into the roof shale for a distance not exceeding 15 to 20 feet. Above this height no cracks are in evidence as the confined rock flows or is deformed.

On the basis of these observations there is little justification for presumptions or theories that the increase in volume of the beds subsiding over longwall workings is sufficient to compensate for the total height of material mined. Apparently the increase in volume is limited to the strata, 10 to 20 feet thick, immediately overlying the coal bed.

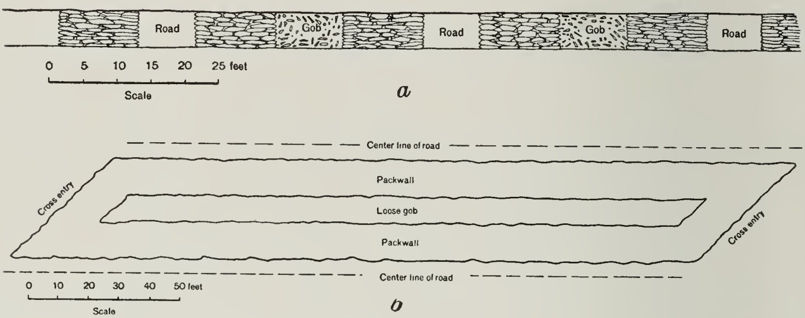

FIG. 53.—*a*, Diagrammatic illustration through the gob and parallel to the face of a longwall mine; *b*, plan showing pack walls and loose gob between roadways and cross entries in the same mine.

The overlying beds are traversed by breaks or cracks "every 2 inches to 6 feet," and it is evident that the greatest increase in volume that can arise will result from the visible breaks or cracks; the increase in volume resulting from invisible cracks may probably be ignored without serious error. If the visible cracks occur every 2 inches to 6 feet, the material, along the roads at least, is obviously broken into slabs 2 inches to 6 feet long, and these slabs settle in fairly orderly fashion upon the filling. Under such conditions any considerable increase in volume of the overlying beds is not conceivable. If, however, the strata higher up do not sink gradually but remain undisturbed for a time, while the beds immediately underlying subside several feet, in time such resistant beds may fail, and large falls may occur with a considerable increase in volume of the broken material. In northern Illinois the average distance between room centers is 42 feet, the roadways are not less than 8 feet wide, and the pack walls are 4 yards wide on each side of the road. The distance between the walls should therefore average about 10 feet. This space, called the "gob," would be filled more or less completely with waste material thrown back as the face is advanced. A cross-section along the face would then show the roof supported as indicated in figure 53 *a*.

There is little probability that the vertical amount of settling over the gob, if not more than 10 feet wide, will be materially greater than the settling over the roads which are 8 to 10 feet wide. Moreover an examination of old roads protected by pack walls or buildings shows that as the roof settles the pack walls are compressed and they tend to bulge and to spread horizontally, as is evidenced by the reduction in the width of roadways. It may logically be inferred that some spreading of the pack walls occurs on the side toward the gob. In time the gob would offer more resistance to settling than do the roadways although these are probably better protected at first, inasmuch as the pack walls are built more substantially on the roadside than on the gob side.

Where roads have been driven through abandoned longwall workings in which the old roads have been closed for years, it has been found on brushing to the necessary height for the new road, that there is but little undulation in the previously horizontal roof shales on account of the settling over the pack walls. If such undulation exists it is undoubtedly much more marked in the strata immediately overlying the coal than in those at a greater height above the coal horizon. From the observations that have been made in the deeper longwall mines in Illinois, where the measures immediately overlying the coal are thick beds of shale, it is apparent that minor irregularities in filling and pack walls have but little effect upon the general subsidence movement; in fact, so little that only the most precise observations may indicate that such irregularities have influenced the general movement. When it is so impracticable, as is usually the case, to secure complete data on the continuity and uniformity of the overlying beds, it seems unwise to attempt to discuss the effect of minor irregularities in the filling and pack walls.

The conditions in the average longwall mine may be, for the purpose of discussion, considered to be as shown in figure 53,*b*. As the longwall face is advanced new cross entries are started and the old ones are abandoned. Where the cross entries are turned at an angle of 45 degrees to the main entry, the distance between cross entries may be from 225 to 300 feet.[7]

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[7]Preliminary report on organization and method: Ill. Coal Mining Investigations Bull. 1, p. 18, 1913.

From these cross entries are turned the roadways to the rooms or working places. These working places will average 42 feet in length along the working face, and the distance from center to center of roadway will be 42 feet. As shown in figure 53, the worked-out area is laid out more or less regularly in a series of parallelograms approximately 225 by 32 to 34 feet. Around the four sides of each parallelogram is a wall of mine rock built 9 to 12 feet thick. Within the four walls the space is at first partly filled with shoveled material,

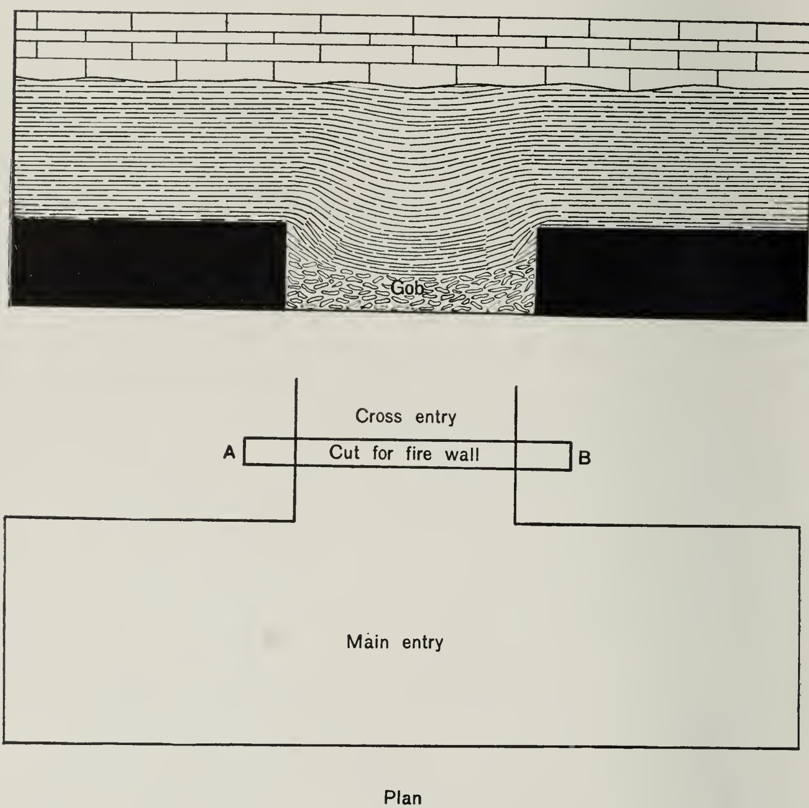

Fig. 54.—Diagrammatic illustration showing the flow of roof shale under pressure in a mine near Peoria.

and later the unfilled space, if any, may be filled by falls of roof rock. After the working face has been advanced a short distance, the roof settles upon the pack walls, and in time as these are pushed down into the underclay the roof within the pack walls may sag and bear upon the gob (fig. 54). When this state is reached, the parallelogram bounded by four pack walls, becomes in reality a long cog with walls built of mine rock, the center being filled with shoveled material.

These cogs tend to prevent surface subsidence. Their success in accomplishing this will depend upon the extent to which the clay bottom heaves in the roads, the amount the pack walls bulge, and the power of the pack walls and the gob to resist compression. As usually built these walls are not rigid.

Normally, when the main entries have been advanced 225 to 300 feet beyond a cross entry, a new cross entry is started, and in time the old cross entries are abandoned. Until they are abandoned sufficient height is maintained to permit the passage of mules. The roads are brushed and the bottom is lifted as long as it is necessary to keep the road open. Though the amount of material thus removed is occasionally large, relatively it represents but a small volume of the material within the parallelograms of rock filling on each side of the road. The bulging of the packs and the flow of the bottom may eventually cease where the material within the cog has been compressed to such an extent that it does not flow easily. After the roads have been abandoned, the amount of flow is limited to the volume of the roadway itself.

For the purpose of this discussion it may be assumed that two longwall mines are operated under identical conditions except that the coal seam in one lies at a depth of 200 feet and the other at 600 feet. The plan of mining, dimensions of rooms, and other factors are the same, and the same amount of material is built into walls and stowed in the gob.

Considering only the matter of compressibility of pack walls and gob, it should be noted that the maximum amount of subsidence which can result in the mine 200 feet deep, is determined by the amount the gob and walls are compressed under the load of 200 feet of overlying strata. If the load were less, the distance through which the roof would sink would be less; and if the load were increased, the distance through which the roof would sink would be increased up to the limit of compressibility of the material in the gob.

As the weight of the overburden increases directly with the depth, therefore the compression of the gob is greater for deep mines than for shallow mines; it is greater for a mine 600 feet deep than for a mine 200 feet deep, other conditions being the same, providing of course that the limit of compressibility of the material has not been reached. It follows logically that so far as the factor of compressibility of filling controls—and in a majority of cases it is the controlling factor—the total amount of vertical movement tends to increase rather than to decrease with the depth of mining.

To this general statement there may be exceptions, and there may be depths beyond which this would not apply; but it is the opinion and the experience of British mining engineers that subsidence will follow longwall mining irrespective of depth. It is generally supposed that there is more or less flow in the rock beds overlying the coal after these beds have stood for a time depending for support upon the pillars or filling. However, it is difficult to find evidences of such flowage on a large scale.

In a mine near Peoria it became necessary to open a section of the mine that had been abandoned and build a fire wall extending up to an overlying limestone. Immediately overlying the 5-foot coal bed is a bed of shale approximately 10 feet thick, and resting on the shale is a stratum of limestone. The roadway from 12 to 15 feet wide, was

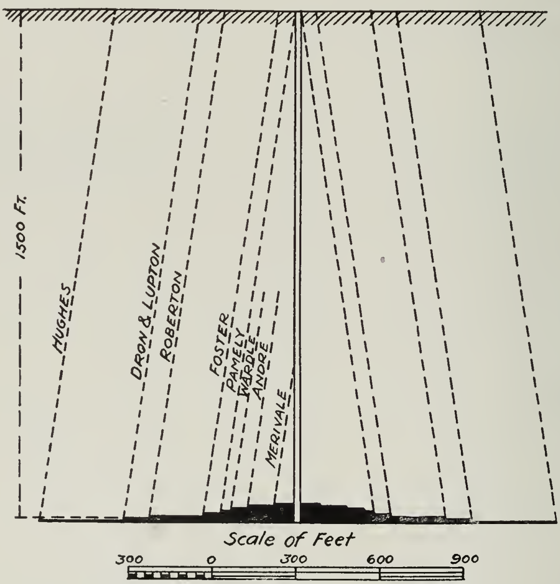

FIG. 55.—Diagrammatic illustration showing to scale the size of shaft pillars for given depths as recommended by various mining engineers.

filled tightly with shale from the overlying bed. A cut through the shale to the limestone showed that the shale had under pressure practically flowed to fill the opening, whereas the overlying limestone showed no breaks or cracks where it was possible to make an examination. The conditions are illustrated by figure 54.

Shaft Pillars

Commonly in determining the size of pillars necessary to protect mine openings of a given width it is customary to assume a span of roof and overlying rock to be supported, to estimate the total weight of such a block for the depth of the workings, and then with the known or assumed unit crushing strength of the material to be left in the pillar, the cross-section may be calculated readily. The dimensions may then be proportioned in order to secure the most economical and safest working conditions; on the same general plan shaft pillars or other important pillars may be determined.

Numerous rules have been formulated for the calculation of shaft pillars in flat seams; a great diversity of opinion prevails among engineers as to the required dimensions at various depths and with different thicknesses of coal seams. This diversity of opinion is well shown[8] graphically by figure 55.

In determining the size of pillar necessary to protect objects upon the surface, as has been noted previously, the ability of the pillar to carry the load is not the only uestion to be considered. Among the most important of the other problems is that of draw or pull over the pillar and the ability of the underlying bed to sustain the load concentrated upon it by the pillar. Quite frequently the underlying bed is less stable and has less crushing strength than the pillar. It seems logical then to proceed as follows in determining the size of pillar necessary to protect an object upon the surface:

1. Determine the lateral extent of pillar necessary in order to prevent damage by draw.
2. Determine whether the pillar thus outlined is sufficiently large to support the burden of the overlying beds without crushing.
3. Determine whether the load upon the pillar will cause the pillar to be forced down into the underlying bed, or cause a flow of the underlying material.

Room Pillars

At various points in Illinois it has been necessary for the coal mining companies to assume responsibility for any surface damage which may result from coal mining and it has been deemed advisable to leave in the ground a sufficient amount of the coal to prevent movement, at least to prevent the movement from extending to the surface.

Where the roof is strong it may stand for some time without breaking, but eventually in parts of the mine at least, movements of the top or bottom may cause a considerable area to be affected. The general theory of the arching of strata has been presented by a French engineer, Fayol.

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[8]Knox, G., Mining subsidence: Proc. International Geological Congress, vol. 12, p. 798, 1913.

In his discussion of methods of protecting the surface, Fayol referred to the use of pillars between the working places. "The meshes of the network consisting of pillars with working places between them should be made smaller as the workings are shallower. As the depth becomes greater the size of the meshes can be enlarged, and the dimensions of the areas worked can be increased relatively to the sizes of the pillars that are abandoned, regard being had to the height and width of the zones of subsidence, so that the various zones may be kept distinct from each other. This general rule is susceptible of many combinations according to the thickness, the inclination, the number, and the depth of the seams worked. If the excavation is of small dimensions the subsidences which take place above them are restricted in size and become enlarged both in width and height as the excavation increases in area. If the pillars at 1, 3, 5, and 7 be taken out (fig. 56), zones of subsidence similar in Z_1, Z_3, Z_5, and Z_7 would be produced; but when pillar 2 is taken out the line of roof subsides on to the floor, and the zone of subsidence rises in Z_2. The same thing happens when

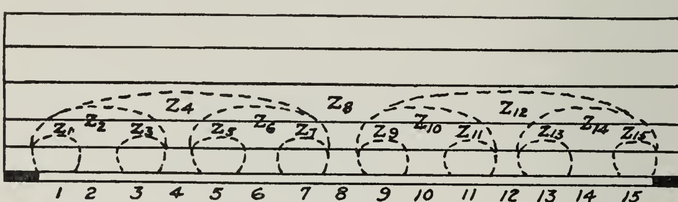

FIG. 56.—Diagrammatic illustration showing the extent of subsidence resulting from the removal of adjacent pillars (after Fayol).

No. 6 pillar is taken out, and if No. 4 pillar is taken out, the space comprised between the zones Z_2 and Z_6 is set in motion and determines the formation of the zone Z_4."[9]

It follows then from this statement of Fayol, that if the room pillars are properly proportioned and properly spaced, the disturbance of the strata may be limited to the volume within the zones. The material outside these zones throws no weight upon the material within the zone. Necessarily then any vertical pressure must fall upon the unmined material forming the pillars, and the pillars must be large enough to withstand this pressure. In stratified beds the problem is more complicated, owing to the fact that the beds act as single members and frequently sag under their own weight.

[9]Proc. South Wales Inst. Eng., vol. 20, p. 340, 1897. It should be noted that these zones outline the dome through which the movement extends, and not the limit of the "falling zone" as described by the Austrian engineer, Rziha.

In a paper before the Pennsylvania State Anthracite Mine Cave Commission, 1913, Mr. Douglas Bunting said, "The application of a formula for determining the safe size of coal pillars for various thicknesses of veins and depths can be considered practical for depths greater than 500 feet, but it is doubtful if the same formula would be of any practical value for application to veins at less depth, and certainly of diminishing practical value with reduction in depth and thickness of veins for the reasons that the variable conditions of vein, top, bottom, and other factors are of more consequence with small pillars than with large pillars."[10] The average dimensions of pillars and rooms in ordinary room-and-pillar mining in Illinois are shown[11] in Table 16.

Table 16.—*Dimensions of rooms and pillars in Illinois coal mines*

District	Average depth	Room width	Pillar width
	Feet	*Feet*	*Feet*
II	140	26	19
III	90	22	18
IV	201	25	9
V	243	26	16
VI	270	22	18
VII	227	31	30
VIII	174	27	8
Average for State	208	26	19

Filling Methods

In a number of important mining districts in America and in Europe, filling methods have been used extensively both to increase the percentage of coal recovery and to reduce the surface movement. These methods are adapted particularly to dipping seams.

GOBBING

Waste material resulting from regular mining operations or broken for this particular purpose may be stowed or packed into the excavation. If sufficient or suitable material is not available underground, it may be lowered or dropped from the surface and stowed where needed.

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[10]Bunting, D., Pillar and artificial support in coal mining with particular reference to adequate surface protection: Pennsylvania Legislative Journal, vol. 5, Appendix, p. 5988, 1913.

[11]Andros, S. O., Coal mining in Illinois: Ill. Coal Mining Investigations Bull. 13, p. 76, 1915.

In the longwall field the waste produced at the working face is stowed in the gob, but usually a large amount of rock resulting from falls and brushing in the roads is hoisted and piled on the surface. Owing to the nature of longwall work it is claimed that it is impracticable to stow much of this material in the gob. It might be done at an increased total cost per ton of coal mined.

In room-and-pillar mining the waste material can be stored underground much more readily than in longwall mining, and in many Illinois room-and-pillar mines practically no rock is hoisted.

The coal beds over the greater part of Illinois lie practically flat and the stowing of material in both room-and-pillar and longwall mining would be expensive on account of the necessity for hauling the filling long distances and because a large amount of shoveling would be required underground.

HYDRAULIC FILLING

The stowing of material by means of water[12] has been employed extensively in a number of mining districts, but is not being employed at any Illinois coal mines. Hydraulic filling seems to be impracticable at present on account of the flatness of the beds, the clay floor, and the difficulty in securing suitable filling material in the coal district. As previously noted, little stone, sand, or gravel is available, and the surface is so valuable for agricultural purposes that the cost of material secured from surface pits would be prohibitive in most places. Deep pits would be impracticable generally, as considerable pumping would be necessary during a number of months in order to keep the pits unwatered. In parts of the State there might be a shortage of water during several months of the year.

GRIFFITH'S METHOD OF FILLING

It has been suggested by Mr. William Griffith that worked-out portions of mines be filled by blasting up the bottom and shooting down the roof. This suggestion was made in connection with a report to the

[12]The Copper Range Consolidated Copper Company, Painesdale, Michigan, is using compressed air to carry filling material for short distances through iron pipe. The material is the ¼-inch "stamp-sand" or crushed waste rock from the concentrating plants which is dropped from the surface through steeply inclined raises to the levels where filling is being carried on. On these levels the material is dropped into cars and hauled to some convenient point above the stope to be filled. The filling material is dumped from the cars into pockets or chutes and is distributed horizontally in the stopes from the bottom of these chutes. It has been found economical to carry the filling material by compressed air not to exceed 300 feet through the pipes. The pipe is shifted laterally, lengthened, shortened, or raised as may be necessary to distribute the material. There are no bends in the pipe and the material is handled dry.

Scranton Mine Cave Commission, and Mr. Griffith has secured a patent (U. S. Patent No. 1,004,418) covering this method.[13]

It has been suggested that by this method an increased percentage of coal could be recovered. So far as known this method has never been applied to beds as flat as those in Illinois. The conditions in Illinois do not lend themselves toward making this scheme practicable as the immediate roof is generally not hard enough to make the proper kind of filling and the bottom is underclay which is too soft to serve as filling that will increase in volume when blasted and in that condition support any weight without being reconsolidated to occupy practically the original volume.

Artificial Supports

At only a few places have artificial supports been introduced to protect objects upon the surface. The construction of cogs was necessary at one place to prevent the collapse of the beds under a railroad right-of-way. The workings were at shallow depth and complete filling seemed to be impracticable though the workings were still accessible. Two types of cogs were used, the more successful being a timber cog filled with mine rock. Masonry, concrete, reinforced concrete, iron, and steel structures have been employed in American and European districts to protect important structures and roads.

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[13]Messrs. Griffith and Connor say, "It is a well-known fact that loose rock occupies from $1\frac{2}{3}$ to twice the volume of the same weight of rock in place. Your engineers have conceived the idea of taking advantage of this fact, well known to engineers, for the purpose of cheaply producing an adequate support of the rock and surface above certain classes of coal beds under the city of Scranton. So far as we know, this method, in its entirety, has never been used before in any coal-mining district, and the suggestion is here made for the first time.

"The process is applicable to beds less than 6 feet in thickness and consists simply in blowing up the floor and shooting down the roof of the mine, each to a depth equal to the thickness of the coal bed. This produces a total thickness of loose rock equal to three times the thickness of the coal. The rock would be well packed together and have great supporting power, and moreover the desired ends would be attained in a comparatively inexpensive manner."—Griffith, William, and Conner, E. T., Mining conditions under the city of Scranton: U. S. Bureau of Mines Bull. 25, p. 57, 1912.

CHAPTER VI—INVESTIGATIONS OF SUBSIDENCE

European

As previously noted a number of investigations have been made in Europe to determine the amount of subsidence which results from mining at various depths and under different geological and mining conditions. Some of these investigations have continued over long periods of years, and a few of them have been organized so that additional data will be secured from year to year. It has been possible, in districts where such observations have been made, to adapt the system of mining so that the maximum recovery of mineral may be made with least damage to the surface. Knowing what effect mining will have upon the surface, it has been possible for several countries to formulate laws and rules for the protection of the owner of the surface and at the same time to secure for the mine owner a just consideration of his rights. The problem of subsidence in Europe has been discussed by the author and Mr. H. H. Stoek in Bulletin 91 of the Engineering Experiment Station, University of Illinois.

United States

In the United States very little work has been done along these lines—practically nothing in the bituminous coal districts. Very few of the data that have been collected are available for the use of the public. The scarcity of data in the bituminous fields may be due largely to the fact that the most extensive mining operations for bituminous coal have been carried on where the surface is mountainous or is of little value for agricultural purposes.

If the percentage of extraction from the flat coal beds of the Middle West is to be increased it seems timely that there should be secured, in more or less typical mining areas, data which will serve to show the amount and extent of subsidence which may be expected to result from mining operations.

Suggested Illinois Investigation

considerations

It has been suggested that in Illinois investigations be made including measurements to determine the surface movement under various conditions and also laboratory tests to determine the strength of rocks forming mine roofs and of materials used for supports. The bearing power of the materials forming the mine floor should also be investigated. The nature and amount of surface subsidence should be studied when different methods of mining are used and when various methods of filling are employed.

TYPICAL MINES

The idea has been advanced by George S. Rice,[1] that typical districts should be selected giving special consideration to the longwall fields. For this work the following may be suggested:

1. Wilmington district where the coal occurs at a depth of 50 to 150 feet.
2. La Salle district where the depth to coal No. 2 is from 300 to 500 feet.
3. Decatur district where coal No. 5 lies at a depth of 500 to 600 feet.
4. Assumption district where coal is mined at a depth of 1,000 feet.

For the investigations in connection with room-and-pillar and panel work the following may be suitable:

1. Springfield district where the coal is mined at a depth of 150 to 200 feet.
2. Williamson County district where mining is at varying depths up to 300 feet.
3. Gillespie-Staunton district with depths of 300 to 400 feet.
4. Franklin County district where the depth of mining is 400 to 700 feet.

MONUMENTS AND SURVEYS

It has been suggested that substantial surface monuments be established in parallel lines across the working face in longwall mines and in room-and-pillar mines across panels that are to be worked. The monuments should be established over the solid coal before any movement has commenced, and the location of these monuments with regard to points underground should be determined accurately. At regular intervals levels should be run, and profiles made along each line of monuments showing the position of the working face, the original position of the surface, and the elevations at the time of the successive surveys.

The monuments should be located where they will be easily accessible to the surveyor but where they will not be interfered with, and they should be so constructed that they will not be lifted by frost. In addition to the levels, measurements should be made from time to time to determine the amount of lateral movement or draw.

UNDERGROUND WORK

It would be essential that a careful record be made of underground conditions. In room-and-pillar and panel work the date of opening rooms, the actual dimensions of pillars, and the position of the rooms with regard to surface monuments should be noted. When rooms are finished and the pillars are drawn, particular attention should be given to movements of roof and floor, and if a squeeze follows, a detailed report should be made as a basis for the study of surface movement and of other squeezes.

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[1]Chief Mining Engineer, U. S. Bureau of Mines, one of the representatives of the Bureau in this cooperation.

After the movement underground has ceased, whatever observations are possible should be made in the vicinity, noting particularly the angle of break in the roof, the condition of pillars, the amount of open space above the falls, and the condition of the roof material which is standing.

In longwall mines the rate of advance should be noted regularly as well as the stability and width of the pack walls, the amount of material placed in the gob, the angle of fracture of roofs, the height to which breaks extend into the roof, the rate of settling of the roof, and the ratio of compression of pack walls. Observations should be made to discover the amount of sag in a direction parallel to the face and between the pack walls.

If practicable the amount of filling in one section of the mine should be kept constant, but a different amount should be used regularly in another part, in order to discover the effect that filling has upon subsidence.[2]

POSSIBLE BENEFITS

From the data secured it should be feasible to determine the amount of subsidence which may be expected per foot of material excavated at different depths and with different geological sections. It should be possible to predict in longwall mining whether the wave of subsidence will move in advance of the mining face or lag behind it. The amount of draw after the advance has ceased could undoubtedly be predicted with more accuracy than is possible at present. The effect of leaving pillars could probably be shown with greater certainty, and it would undoubtedly be possible to protect such structures as must be left undisturbed with less interference with mining operations.

As previously noted, nearly one-half the coal is being left in the ground and made unavailable for future mining. At present the lost coal in the mines of southern Illinois represents a larger tonnage of coal per acre than there is in the virgin coal seam now being mined in northern Illinois, and each ton of this abandoned coal has a heating value of 7 to 8 per cent greater than the coal mined in northern Illinois.[3]

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[2]This might be feasible in a mine in which the undercutting is done in part by hand and in part by machines. In one mine the ratio between the volume of material removed in the undercutting by machine is about one-fourth as much as in undercutting by hand.

[3]The average analysis of 58 samples of coal No. 6 from east of the Duquoin anticline showed a heating value of 11,825 B. t. u. The extraction of 56 per cent of the seam which averages 9 feet in thickness results in leaving 6,732 tons to the acre. In northern Illinois the average thickness of the coal mined is 3 feet 2 inches, and the average heating value, as indicated by 38 samples, is 10,981 B. t. u. In other words, in northern Illinois the virgin coal seam contains per acre 5,700 tons of coal of 10,981 B. t. u., whereas in District VI the average worked-out mine contains 18.1 per cent more coal of a heating value 7.7 per cent greater than does the unworked tract in northern Illinois.

It is hoped that a careful study of the subsidence problem in the various mining districts will lead to a better realization of the necessity to the State for extraction of the coal where the damage to the surface will be reparable. Where the damage to the surface is reparable and in excess of the value of the coal, the facts should be made known and the proper steps taken. Where the damage to the surface is irreparable and in excess of the value of the coal, it seems advisable to stop the mining of coal completely until such time as the increased value of coal may be sufficient to warrant the renewal of mining and the complete extraction of the coal possibly under improved methods of mining.[4]

The State should give attention to the problem of conservation in those extensive areas of coal fields where the right to the coal is held by one party and the surface by another, but under the existing deed the owner of the coal is held liable for any surface damage resulting from mining operations. Under such conditions it may be expected that nearly 50 per cent of the coal will be left in the ground. Against this practice a protest may well be raised and the State of Illinois should find or create a remedy.[5]

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[4]George S. Rice, in an informal address in New York, in 1913, before the American Institute of Mining Engineers, stated that he had been shown leveling data in Upper Silesia, Germany, relating to surface elevations in and about a certain important iron works, which showed that where granulated slag had been hydraulically stowed in coal-mine excavations, in a bed 20 feet thick in which there had been practically complete extraction of coal, the subsidence had not been appreciable, at the maximum point showing only 2½ inches. Also that since the hydraulic stowing system had been inaugurated in Westphalia the German government had allowed mining under important munition manufacturing buildings at the Krupp works in Essen, whereas formerly under the old dry-filling methods there had been serious subsidence in and about parts of Essen resulting in cracked walls and buildings which he had observed in 1911.

[5]It has been suggested that a tax be levied upon coal left in the ground. This might be done by assessing the land or coal right upon the full tonnage originally in the ground less the amount which has actually been recovered, and continuing this assessment against the land until the unmined coal is recovered. If this were to become the general practice it would undoubtedly tend to induce the mining companies to remove more of the coal.

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